# CONTENTS

# FIGURES

## FIGURES (continued)



## TABLES

# 2. SITE BACKGROUND

Section 2 provides detailed information about the Idaho National Laboratory (INL) Site, including historical information about evolving missions, physical landscape, flora and fauna, demography, land use, and cultural resources. This information applies to the INL Site in general and then, as indicated in subsequent headings, to the Radioactive Waste Management Complex (RWMC) specifically. Originally established in 1949 as the National Reactor Testing Station, the INL Site is a U.S. Department of Energy (DOE) -managed reservation that historically has been devoted to energy research and related activities. The National Reactor Testing Station was redesignated as the Idaho National Engineering Laboratory in 1974 to reflect the broad scope of engineering activities taking place at various facilities. In 1997, the Idaho National Engineering Laboratory was renamed the Idaho National Engineering and Environmental Laboratory to emphasize environmental research. In mid-2003, the Idaho National Engineering and Environmental Laboratory was restructured into two separate business units: one for laboratory research and development missions (i.e., INL) and one for cleanup activities (i.e., Idaho Cleanup Project [ICP]). In February 2005, the two business units came under the management of two separate contractors, and the name of the laboratory was changed to INL in keeping with its multiple uses (Litus and Shea 2005). This separation allows each organization to focus on its distinct mission: (1) major mission realignment of INL as the lead laboratory for U.S. nuclear energy research and (2) the ICP mission to focus on environmental remediation and cleaning up historic contamination at the INL Site as quickly and efficiently as possible (Litus and Shea 2005).

Historical testing at the INL Site demonstrated that nuclear power could be used safely for generating electricity and for other peaceful applications. More nuclear reactors and a wider variety of reactor types have been built at the INL Site than at any other single location in the world (Irving 1993). As of March 2006, three reactors operate at the INL Site: Advanced Test Reactor and Advanced Test Reactor-Critical Facility at the Reactor Technology Complex (RTC), and Neutron Radiography Reactor at the Materials and Fuels Complex.

Current environmental remediation activities at the INL Site are being carried out by ICP under the management of CH2M-WG, Idaho, LLC. These remediation activities include treating, storing, and disposing of waste; removing or deactivating facilities that are no longer of value; cleaning up historical contamination that presents risk to human health or the environment; preserving cultural resources; and providing long-term stewardship (Litus and Shea 2005).

Battelle Energy Alliance is managing research and development of nuclear power at the INL Site. The future mission of the INL Site is to (1) ensure secure energy for the United States with safe, competitive, and sustainable energy systems and (2) develop unique national and homeland security capabilities (INL 2005).

Four federal government contractors operate facilities at the INL Site. Bechtel Bettis operates the Naval Reactors Facility; Bechtel BWXT Idaho, LLC, manages the Advanced Mixed Waste Treatment Project; CH2M-WG, Idaho, LLC, manages ICP; and Battelle Energy Alliance manages national laboratory functions and operates INL Site services. These contractors conduct various programs at the INL Site under supervision of two DOE offices: the DOE Idaho Operations Office (DOE-ID) and the DOE-Pittsburgh Naval Reactors Office. The DOE-ID authorizes all government contractors to operate at the INL Site. A variety of programmatic and support services provided by Battelle Energy Alliance are related to nuclear reactor design and development, nonnuclear energy development, and materials testing and evaluation. CH2M-WG, Idaho, LLC, provides services related to operational safety, radioactive waste management, and environmental restoration.

## 2.1 Location and Description

The INL Site is located in southeastern Idaho (see Figure 1-1) and occupies 2,305 $km^2$ (890 $mi^2$) in the northeastern region of the Snake River Plain. Regionally, the INL Site is nearest to the cities of Idaho Falls and Pocatello and to U.S. Interstate Highways I-15 and I-86. The INL Site extends nearly 63 km (39 mi) from north to south, is about 58 km (36 mi) wide at its broadest southern portion, and occupies parts of five southeastern Idaho counties: Butte, Bingham, Bonneville, Jefferson, and Clark. Most of the INL Site lies within Butte County. Approximately 95% of the INL Site has been withdrawn from public domain. The remaining 5% includes public highways (i.e., U.S. 20 and 26 and Idaho 22, 28, and 33) and the Experimental Breeder Reactor I, which is a national historic landmark (Irving 1993). Neighboring lands are used primarily for farming and grazing or are in public domain (e.g., national forests and state-owned land).

Lands acquired for the INL Site were originally under control of the U.S. Bureau of Land Management and were withdrawn through public land orders in 1946, 1949, and 1950. Until these withdrawals, the land was used primarily as rangeland. Between 121,410 and 141,645 ha (300,000 and 350,000 acres) within the perimeter of the INL Site has been open to grazing through permits administered by the U.S. Bureau of Land Management. Since 1957, grazing has not been permitted in the central area of the INL Site. Covering approximately 1,386 $km^2$ (535 $mi^2$), this central area has been used historically as bombing and gunnery ranges. Currently, the largely undeveloped central portion of the INL Site is reserved for ecological studies of sagebrush-steppe ecosystems.

## 2.2 Physical Characteristics

This section provides information about the INL Site and surrounding region, including maps and narratives describing the general physical features of the surface and subsurface, weather, seismic activity and hazards, and surface and subsurface hydrology.

### 2.2.1 Physiography

The Snake River Plain, a large topographic depression, is the largest continuous physiographic feature in southern Idaho. The plain extends from the Oregon border across Idaho to Yellowstone National Park and northwestern Wyoming. The Snake River Plain slopes upward from an elevation of about 762 m (2,500 ft) at the Oregon border to more than 1,981 m (6,500 ft) at Henry's Lake near the Montana–Wyoming border (Becker et al. 1996). The eastern portion of the Snake River Plain, contained within the Columbia Plateau geologic province, is bounded on the north and east by the Rocky Mountain province and on the south by the Basin and Range province. The INL Site is located entirely on the northern side of the broad eastern Snake River Plain and adjoins the Lost River, Lemhi, and Beaverhead mountain ranges to the northwest (see Figures 1-1 and 2-1).

The part of the Snake River Plain occupied by the INL Site may be divided into three minor physical provinces: a central trough that extends from southwest to northeast through the INL Site and two flanking slopes that descend to the trough (one slope from the mountains to the northwest and the other from a broad lava ridge on the plain to the southeast). Slopes on the northwestern flank of the trough are mainly alluvial fans originating from sediment from Birch Creek and Little Lost River. Basalt flows that spread onto the plain also formed these gentle slopes. Land formations on the southeastern flank of the trough were created by basalt flows that spread from an eruption zone that extends northeastward from Cedar Butte. Lavas that erupted along this zone built up a broad topographic swell directing the Snake River to its current course along the southern and southeastern edges of the plain. This ridge separates surface drainage of mountain ranges northwest of the INL Site from the Snake River. Big Southern Butte and Middle and East Buttes are aligned roughly along this zone; however, these buttes were formed by viscous rhyolitic lavas extruded through the basaltic cover and are slightly older than the surface basalt of the plain.

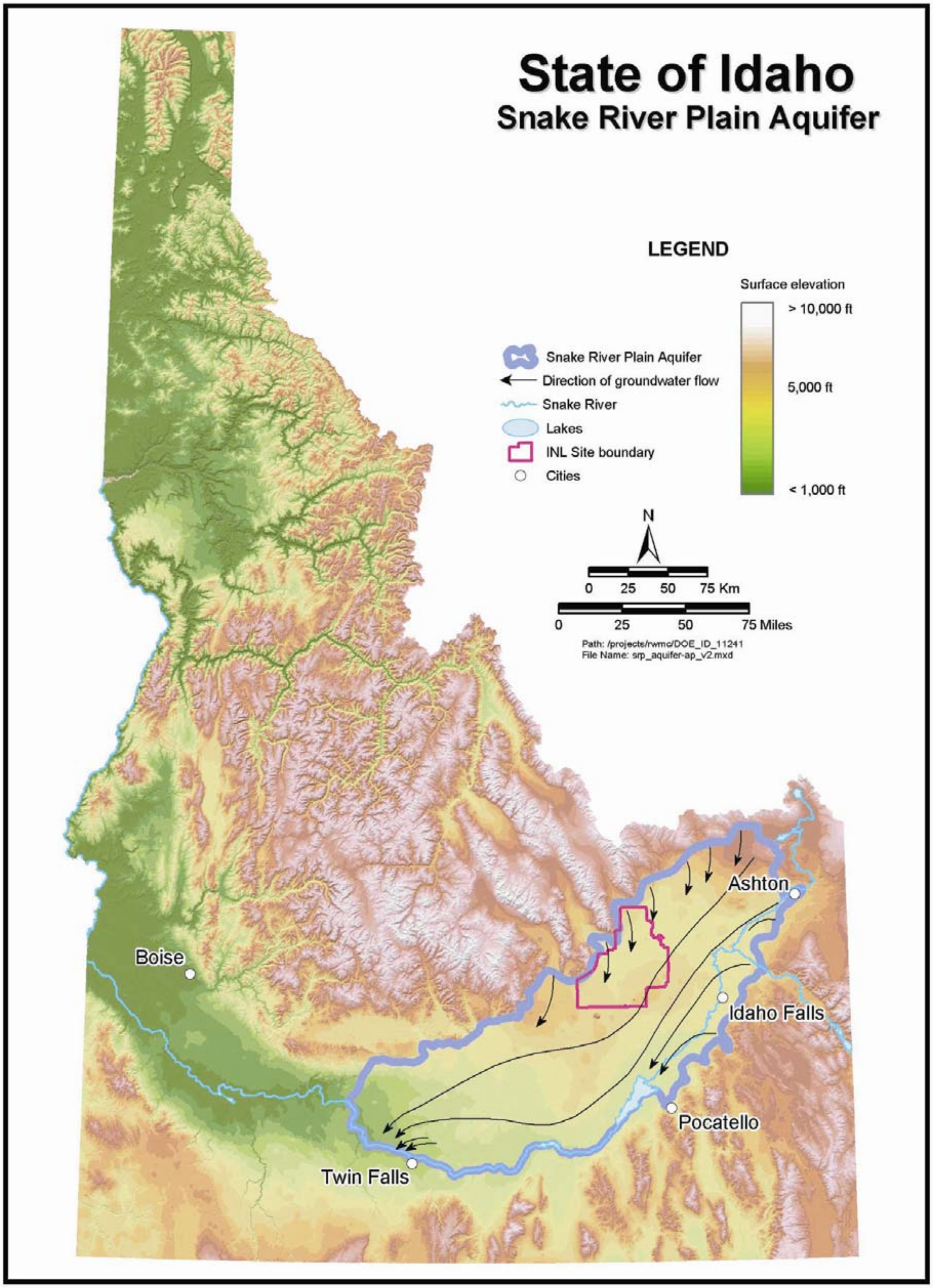



Figure 2-1. Idaho National Laboratory Site on the Snake River Plain Aquifer.

With the exception of the buttes on the southern border, elevations on the INL Site range from 1,460 m (4,790 ft) in the south to 1,802 m (5,913 ft) in the northeast, with an average elevation of 1,524 m (5,000 ft) above sea level (INEL 1988). East, Middle, and Big Southern Buttes have elevations of 2,003 m (6,571 ft), 1,948 m (6,389 ft), and 2,304 m (7,559 ft) above sea level, respectively (Van Horn, Hampton, and Morris 1995).

The central lowland of the INL Site broadens to the northeast and joins the extensive Mud Lake Basin. Big and Little Lost Rivers and Birch Creek drain into this trough from valleys in the mountains to the north and west. Intermittently flowing waters of Big Lost River have formed a flood plain in this trough, consisting primarily of sand and gravel. Streams intermittently flow to the Lost River Sinks, a system of playa depressions (i.e., ephemeral lakes that have water only during parts of the year or once in several years) in the northern portion of the INL Site, east of the town of Howe, Idaho. At the Lost River Sinks, the water evaporates, transpires, or recharges the aquifer. Sinks cover several hundred acres, are flat, and consist of thick layers of fluvial and lacustrine sediment.

The RWMC is located in the southwestern portion of the INL Site, southeast of the diversion dam on Big Lost River and east and northeast of the flood control spreading areas (see Figure 2-2). The RWMC lies within a local topographic depression circumscribed by basaltic ridges. Local elevations range from a low of 1,517.3 m (4,978 ft) to a high of 1,544.7 m (5,068 ft). Topographic features of RWMC and the surrounding terrain are illustrated in Figure 2-3. Enclosed by a constructed containment dike, RWMC has been recontoured on many occasions because of disposal and retrieval operations, remedial actions, subsidence mitigation, and surface drainage modifications. In several cases, sediment from spreading areas was used to augment native soil.

### 2.2.2 Meteorology and Climatology

Meteorological and climatological data for the INL Site and surrounding region are collected and compiled from over 30 meteorological stations operated by the National Oceanic and Atmospheric Administration field office in Idaho Falls. Thirteen of these stations are located on the INL Site. The station at RWMC has collected data since 1993. However, the station at the Central Facilities Area (CFA) has operated since 1949 and has accumulated a more extensive historical record than the RWMC station. Facility-specific data for RWMC are very similar to those representing the southern portion of the INL Site collected at CFA. Because of topographical similarity and proximity of Waste Area Group 7 to CFA, data from the CFA meteorological station sufficiently describe meteorological conditions at the Subsurface Disposal Area (SDA) (Magnuson 1993).

***2.2.2.1 Precipitation.*** The location of the INL Site in the eastern Snake River Plain (e.g., altitude above sea level, latitude, and intermountain setting) affects the climate of the INL Site. Air masses crossing the plain first traverse a mountain barrier and precipitate a large percentage of inherent moisture. Therefore, annual rainfall at the INL Site is light, and the region is classified as arid to semiarid. Average annual precipitation at the INL Site is 21.4 cm (8.44 in.). Rates of precipitation are highest during May and June and lowest in July. Normal winter snowfall occurs from November through April, though occasional snowstorms occur in May, June, and October. Snowfall at the INL Site ranges from a low of about 17.3 cm (6.8 in.) per year to a high of about 151.6 cm (59.7 in.) per year, and the annual average snowfall is 66.0 cm (26.0 in.) (Clawson, Hukari, and Ricks 2005).

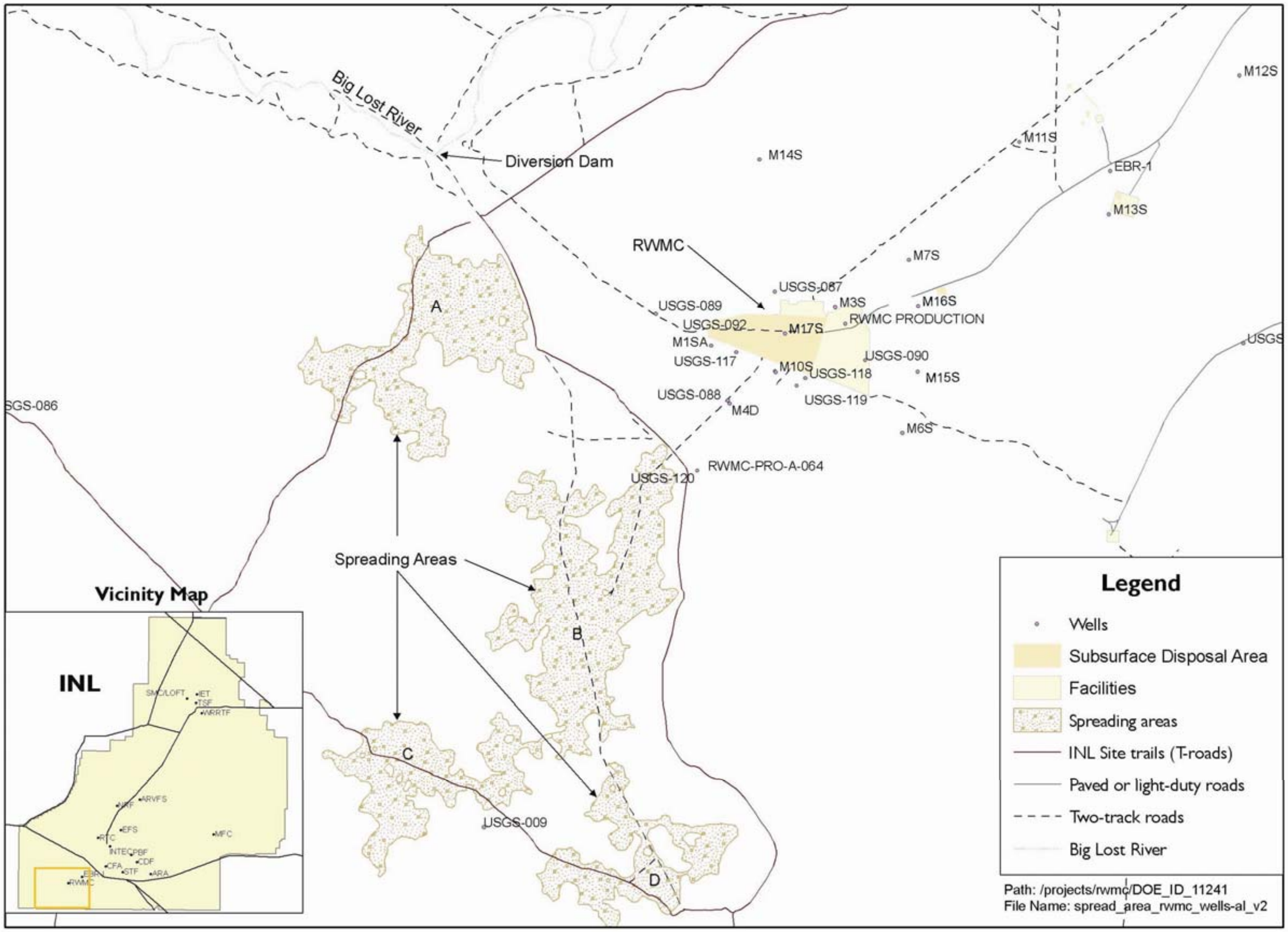



Figure 2-2. Radioactive Waste Management Complex relative to the Idaho National Laboratory Site, the diversion dam on Big Lost River, and the flood control spreading areas.

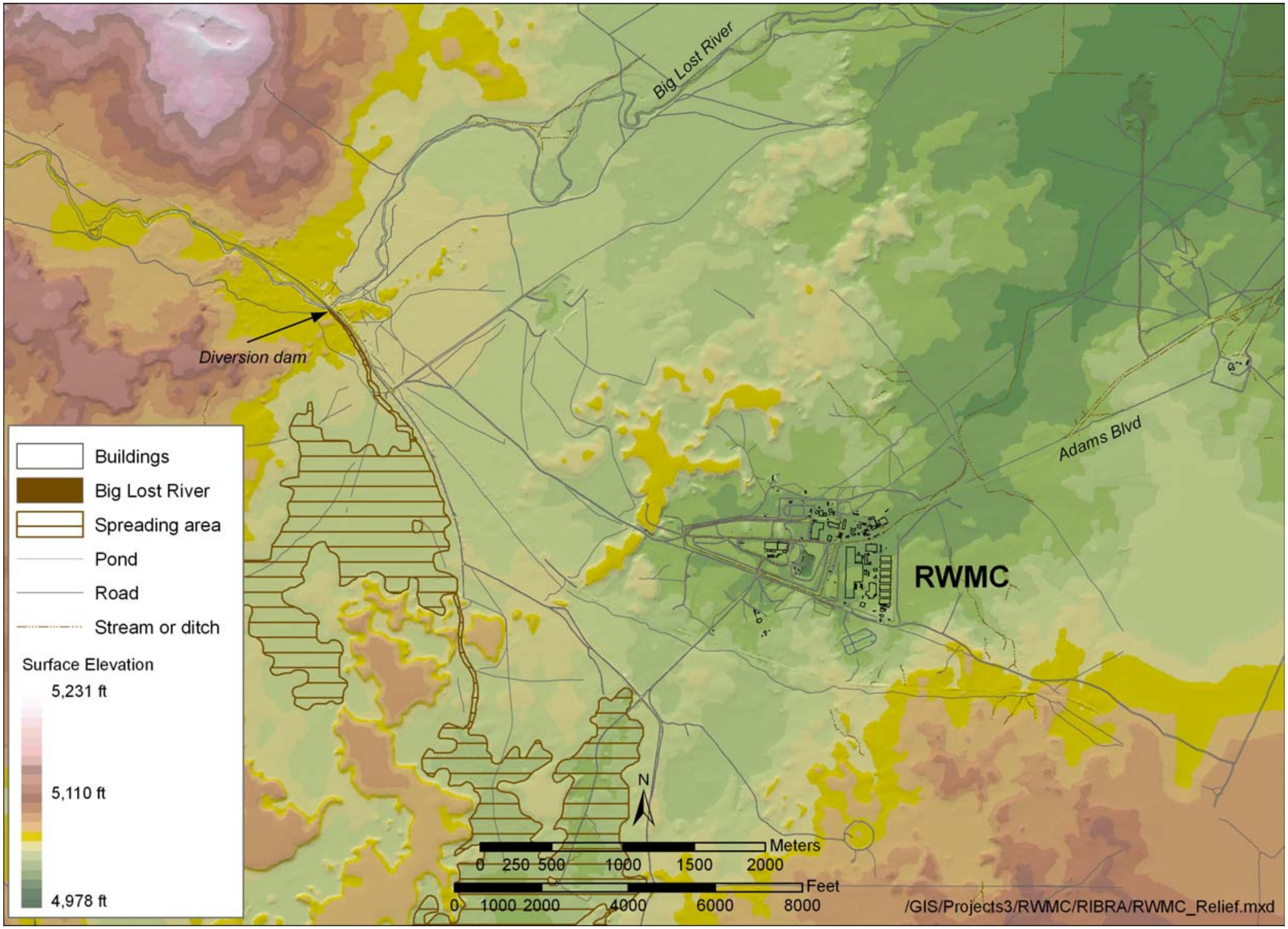



Figure 2-3. Topographic features of the Radioactive Waste Management Complex and surrounding terrain.

***2.2.2.2 Temperature.*** The moderating influence of the Pacific Ocean produces a climate at the INL Site that is usually warmer in winter and cooler in summer than is found at locations of similar latitude in the United States east of the Continental Divide. The Centennial Mountain Range and Beaverhead Mountains of the Bitterroot Range, both north of the INL Site, act as an effective barrier to movement of most of the intensely cold winter air masses entering the United States from Canada. Occasionally, however, cold air spills over the mountains and is trapped in the plain. The INL Site then experiences below-normal temperatures for periods lasting from 7 to 10 days. Relatively dry air and infrequent low clouds permit intense solar heating of the surface during the day and rapid radiant cooling at night. These factors combine to give a large diurnal range of temperature near the ground. Summer daytime maximum temperatures average 28°C (83°F), while winter daytime maximum temperatures average -0.6°C (31°F). Meteorological records from CFA from 1950 through 2004 show temperature extremes at the INL Site varying from a low of -44°C (-47°F) in December to a high of 40.6°C (105°F) in July (Clawson, Hukari, and Ricks 2005).

***2.2.2.3 Humidity.*** Data collected from 1993 through 2005 indicate that average annual relative humidity at the INL Site is 61%. Annual extremes for the same period range from an average minimum of 38% to an average maximum of 84%. Relative humidity is directly related to diurnal temperature fluctuations. Relative humidity reaches a maximum just before sunrise (the time of lowest temperature) and a minimum in midafternoon (time of maximum daily temperature) (Clawson, Hukari, and Ricks 2005).

Potential annual evaporation from saturated ground surface at the INL Site is approximately 109 cm (43 in.), with a range of 102 to 117 cm (40 to 46 in.) (Clawson, Start, and Ricks 1989). About 80% of this evaporation occurs between May and October. During the warmest month, July, the potential daily evaporation rate is approximately 0.63 cm/day (0.25 in./day). During the coldest months, December through February, evaporation is low and may be insignificant. Actual evaporation rates are much lower than potential rates because the ground surface is rarely saturated. Evapotranspiration by sparse native vegetation of the Snake River Plain is estimated to be 15 to 23 cm/year (6 to 9 in./year), or four to six times less than potential evapotranspiration. Periods when the greatest quantity of precipitation is available for infiltration (i.e., late winter to spring) coincide with periods of relatively low evapotranspiration rates (DOE 1981).

***2.2.2.4 Wind.*** Wind patterns at the INL Site are complex. Orientation of the surrounding mountain ranges and the eastern Snake River Plain play an important part in determining wind patterns. The INL Site is in the belt of prevailing westerly winds, which are channeled within the plain to produce a west–southwest or southwest wind approximately 40% of the time. Local mountain valley features strongly influence wind flow under other meteorological conditions as well. Diurnal trends are evident during the night, when cooling of near-surface air along mountain slopes generates winds primarily from north-northeast. A reverse flow, from south-southeast, occurs during the day, when near-surface air along the mountain slopes is heated (Clawson Start, and Ricks 1989). The average midspring wind speed recorded at the CFA meteorological station at 6 m (20 ft) was 9.3 mph, while the average midwinter wind speed recorded at the same location was 5.1 mph (Irving 1993). A wind rose, based on wind direction and speed data collected at the RWMC meteorological station, is provided in Figure 2-4 (Clawson, Hukari, and Ricks 2005).

The INL Site is subject to severe weather episodes throughout the year. Thunderstorms occur mostly during spring and summer. Tornado probability is about 7.8E-05 per year for the INL Site area (Bowman et al. 1984). Two to three thunderstorms, on average, occur during each month from June through August (DOE 1981). Thunderstorms often are accompanied by strong gusty winds that may produce local dust storms. Precipitation from thunderstorms at the INL Site is generally light. Occasionally, however, rain resulting from a single thunderstorm on the INL Site exceeds the average monthly total precipitation (Bowman et al. 1984).

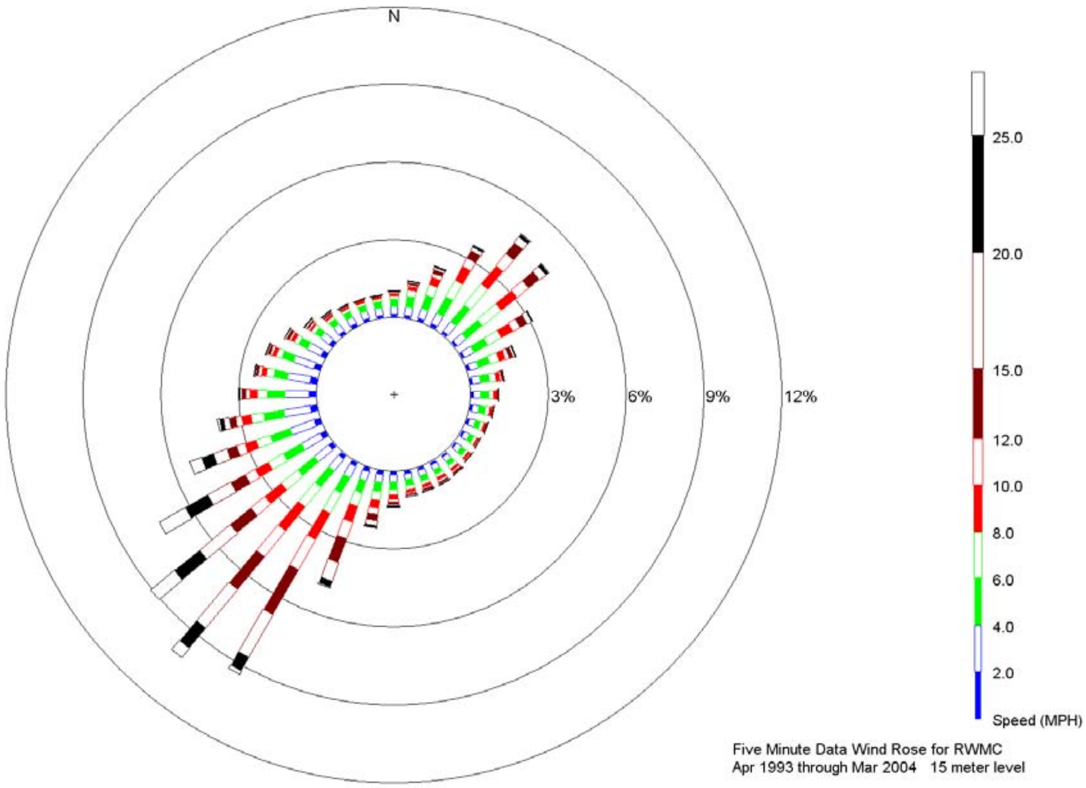



Figure 2-4. Wind rose from the Radioactive Waste Management Complex area from 1980 to 2004.

Dust devils are common in the region and usually occur on warm sunny days with little or no wind. Dust devils can entrain dust and pebbles and transport them over short distances. The dust cloud from a dust devil may be several hundred yards in diameter and extend several thousand feet in the air (Clawson, Start, and Ricks 1989).

### 2.2.3 Regional Surface and Subsurface Geology

The surface of the INL Site is a relatively flat, semiarid sagebrush desert covered by Pleistocene and Holocene basalt flows ranging in age from 300,000 to 3 million years (Hackett, Pelton, and Brockway 1986). Predominant relief comprises volcanic buttes jutting up from the desert floor and unevenly surfaced basalt flows or flow vents and fissures. These basalts erupted mainly from northwest-trending volcanic rift zones, marked by belts of elongated shield volcanoes and small pyroclastic cones, fissure-fed lava flows, and noneruptive fissures or small displacement faults (Hackett and Smith 1992).

A prominent geologic feature of the INL Site is the flood plain of the Big Lost River. Alluvial sediment of Quaternary age occurs in a band that extends across the INL Site from southwest to northeast. Alluvial deposits grade into lacustrine deposits in the northern portion of the INL Site where the Big Lost River enters a series of playas. Paleozoic sedimentary rock makes up a small area along the northwestern boundary of the INL Site. Three large silicic domes (i.e., East, Middle, and Big Southern Buttes) protrude along the southern boundary of the INL Site, and a number of smaller basalt cinder cones occur across the INL Site. Mountains of the Lost River, Lemhi, and Bitterroot ranges (see Figure 1-1) that border the northwestern part of the INL Site are Cenozoic fault blocks composed of Paleozoic limestone, dolomite, and shale. The northwestern trend of the Basin and Range faults (north and at the volcanic rift zones on the eastern Snake River Plain) are controlled by the east–northeast direction of regional extension (Smith, Jackson, and Hackett 1996; Parsons, Thompson, and Smith 1998).

Basalt flows in the surface and subsurface at the INL Site were formed by three general methods of plains-style volcanism, which is an intermediate style between flood basalt volcanism of the Columbia Plateau and basaltic shield volcanism of the Hawaiian Islands (Greely 1982; Hackett and Smith 1992). The methods are flows forming low-relief shield volcanoes, fissure-fed flows, and major tube-fed flows with other minor flow types. Very low shield volcanoes, with slopes of about 1 degree, overlap in their formation. This overlapping and coalescing of flows is characteristic of low surface relief on the eastern Snake River Plain (Greely 1982). Individual basalt flows vary considerably in texture. In general, bases of basalt flows are glassy to fine-grained and minutely vesicular. Midportions of basalt flows are typically coarser grained with fewer vesicles than the top or bottom of the flow. Upper portions of flows are fine grained and highly fractured with many vesicles. This pattern is the result of rapid cooling of the upper and lower surfaces, with slower cooling of the interior of the basalt flow. The massive interiors of basalt flows are typically jointed with vertical joints in a hexagonal pattern formed during cooling.

Sediment was deposited on the surface of basalt flows during quiescent periods between volcanic eruptions. These sedimentary deposits display a wide range of grain-size distributions, depending on the mode of deposition (i.e., eolian [windblown silt or sand], lacustrine, or fluvial; source rock; and length of transport). Because of the irregular topography of basalt flows, sedimentary materials commonly accumulated in isolated depressions.

Wells have been drilled within the INL Site to monitor groundwater levels and water quality. Lithologic and geophysical logs were made for most of the wells. From these logs, and an understanding of the volcanism of the Snake River Plain, a reasonably comprehensive picture of subsurface geology can be drawn. Figures 2-5 and 2-6 are cross sections through the SDA area that illustrate layered geology of thin sedimentary interbeds between large basalt flows.

### 2.2.4 Radioactive Waste Management Complex Surface and Subsurface Geology

The RWMC lies within a natural topographic depression (see Figure 2-3). Undisturbed surficial sediment at RWMC consists primarily of fine-grained playa and alluvial material (Kuntz et al. 1994) and ranges in thickness from 0.6 to 7.0 m (2 to 23 ft). This shallow sediment rests on a thick sequence of basalt flows that are intercalated with thin sedimentary interbeds.

Most of the lava flows are younger than 500,000 years and originated from vents in the Arco-Big Southern Butte Volcanic Rift Zone. This zone is a northwest-trending array of eruptive and noneruptive fissures, grabens, and extensional faults that extends approximately 50 km (18.6 mi) from the northwestern margin of the eastern Snake River Plain at Arco to the Cedar Butte lava field (see Figure 2-7). This vent corridor may have implications for groundwater movement because near-vent volcanic deposits and fissures probably provide either localized preferential pathways or barriers to groundwater flow (Kuntz et al. 2002).

Anderson and Lewis (1989) defined 10 basalt flow groups and seven major sedimentary interbeds underlying RWMC, as shown in Figures 2-5 and 2-6. Basalt flows at RWMC are typical eastern Snake River Plain basalt and occur as layered flow groups. Maximum measured flow thickness is 12.2 m (40 ft), with averages ranging from 1.5 to 5.2 m (5 to 17 ft) (Anderson and Lewis 1989). Using the nomenclature of Anderson and Lewis (1989), these basalt flow groups are named by letter (e.g., A, B, C, and D) corresponding to the stratigraphic sequence of each group, starting from the land surface and moving downward. Sedimentary interbeds are named for the basalt flow groups that bound the layers above and below. Thus, the three uppermost sedimentary layers are designated the A-B, B-C, and C-D sedimentary interbeds, but are also commonly referred to as the 30-, 110-, and 240-ft interbeds, corresponding to average depths from the surface. In the RWMC area, these interbeds consist of generally unconsolidated sediment, cinder, and breccia; thickness averages 3.4 m (11 ft), 4.0 m (13 ft), and 5.2 m (17 ft) for the A-B, B-C, and C-D interbeds, respectively (Anderson and Lewis 1989). Of these three uppermost interbeds, the C-D interbed is by far the most continuous. However, each of the interbeds contains known gaps. The A-B interbed is very discontinuous and generally exists only beneath the northern half of the SDA.

### 2.2.5 Seismic Activity

The seismically active Intermountain Seismic Belt and Centennial Tectonic Seismic Belt surround the eastern Snake River Plain. Seismic activity in eastern Idaho is concentrated along the Intermountain Seismic Belt, which extends more than 1,287 km (800 mi) from southern Arizona through eastern Idaho to western Montana. The RWMC is subject to the same seismic influences. The Centennial Seismic Belt extends from central Idaho into southwestern Montana.

A historical catalog has been compiled from regional seismic networks for earthquakes within a 322-km (200-mi) radius of the INL Site that had magnitudes 2.5 and greater and occurred from 1872 to 2004 (see Figure 2-8). This distribution of epicenters indicates that the Snake River Plain is devoid of earthquakes relative to the surrounding active areas, with the possible exception of the 1905 earthquake at Shoshone, Idaho (INEL 1996). Historical records suggest that the epicenter for the 1905 earthquake is not located within the Snake River Plain but rather near the Idaho-Utah border.

The INL has maintained a seismic network for monitoring earthquake activity on and around the eastern Snake River Plain since December 1971. Currently, the seismic network consists of 27 seismic stations and 25 strong-motion accelerographs. Seismic stations continually record seismic data, which are used to calculate locations and magnitudes of earthquakes that occur locally. When triggered, strong-motion accelerographs record earthquake ground motions within INL Site buildings or free field sites that may be generated by local moderate-to-large earthquakes. Two strong-motion accelerographs are located near RWMC.

The INL seismic network has compiled earthquake epicenters for all magnitudes within 161 km (100 mi) of the INL Site occurring from 1972 to 2004 (see Figure 2-9). During this period, approximately 30 microearthquakes were located within the eastern Snake River Plain, indicating that infrequently occurring, small-magnitude earthquakes (i.e., magnitude less than 1.5) are characteristic of seismicity within the eastern Snake River Plain (Jackson et al. 1993; Pelton et al. 1990). These data are consistent with historical earthquake data for the surrounding region (see Figure 2-8).

A large earthquake in the vicinity of the INL Site, but outside the eastern Snake River Plain, occurred in the Centennial Seismic Belt on October 28, 1983, with a surface-wave magnitude of 7.3 (see Figure 2-8). The earthquake resulted from slippage along the Lost River Fault—a northwestern rupture along a normal fault with relative vertical movement downward to the southwest. The epicenter for this event was located in the Thousand Springs Valley near the western flank of Borah Peak, approximately 89 to 97 km (55 to 60 mi) from INL Site facilities. Masonry structures in Mackay and Challis, near the epicentral area, sustained substantial damage. Although earthquake ground motions were felt at the INL Site, only minor damage occurred in the form of hairline cracks and settlement to nonnuclear buildings (Gorman and Guenzler 1983). The RWMC did not experience structural failures or waste spills because of the earthquake, and waste storage facilities did not show evidence of permanent movement or resulting damage. Peak ground accelerations ranging from 0.022 to 0.078 m/s/s were recorded at several INL Site facility areas. The INL Site is located in the Modified Mercalli Intensity Zone VI where the earthquake occurred (Jackson 1985).

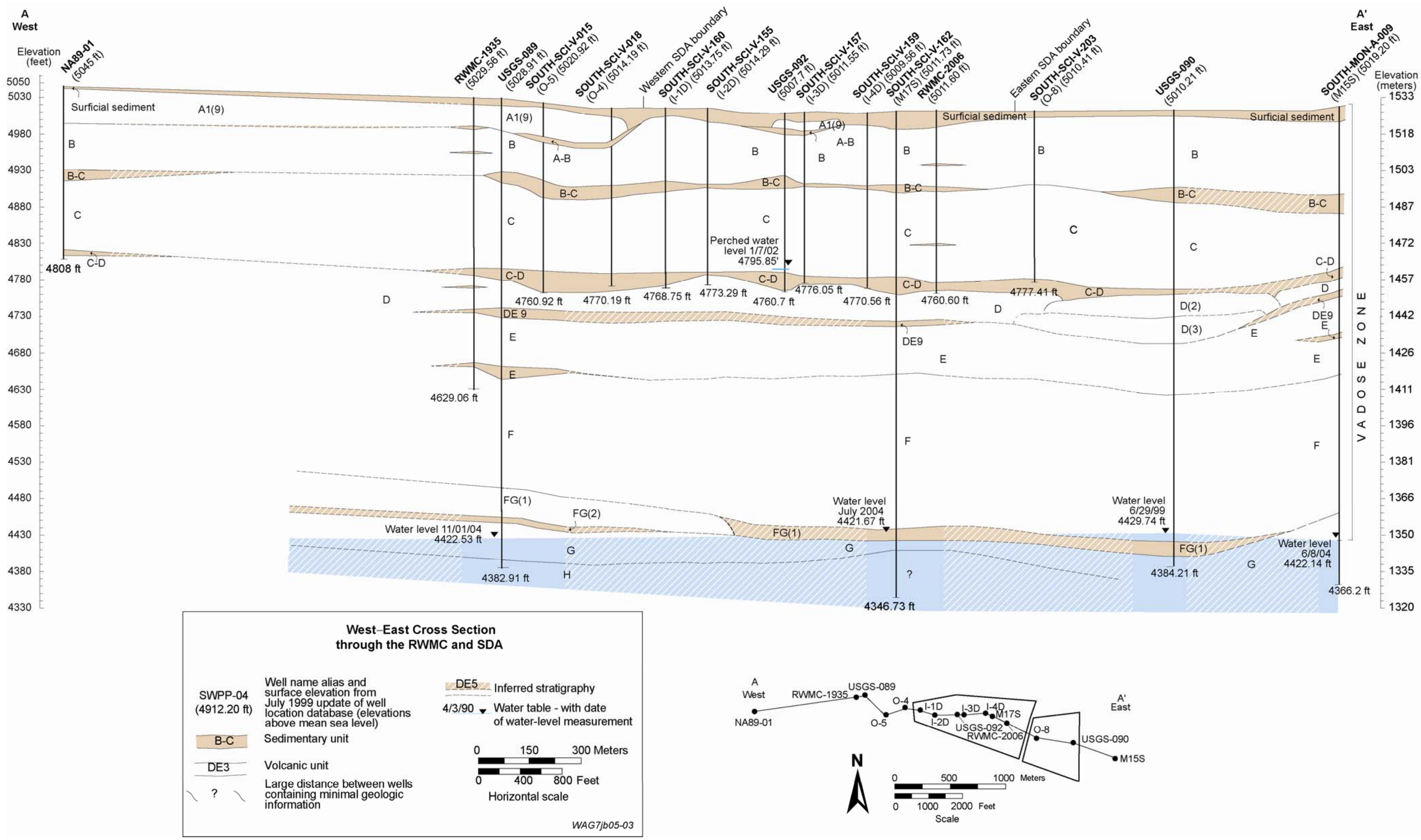



Figure 2-5. Cross section trending west to east through the Subsurface Disposal Area.

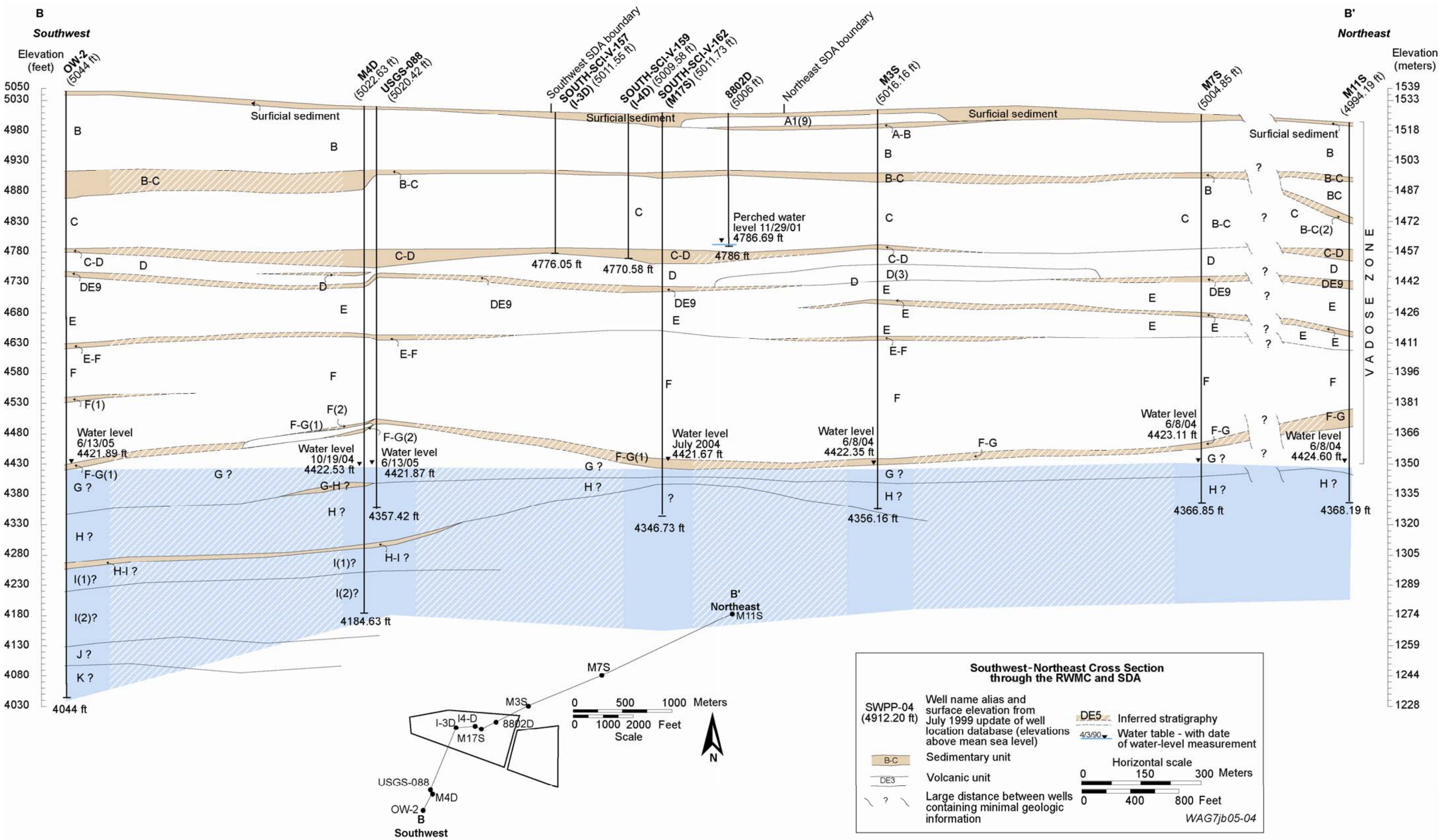



Figure 2-6. Cross section trending southwest to northeast through the Subsurface Disposal Area.

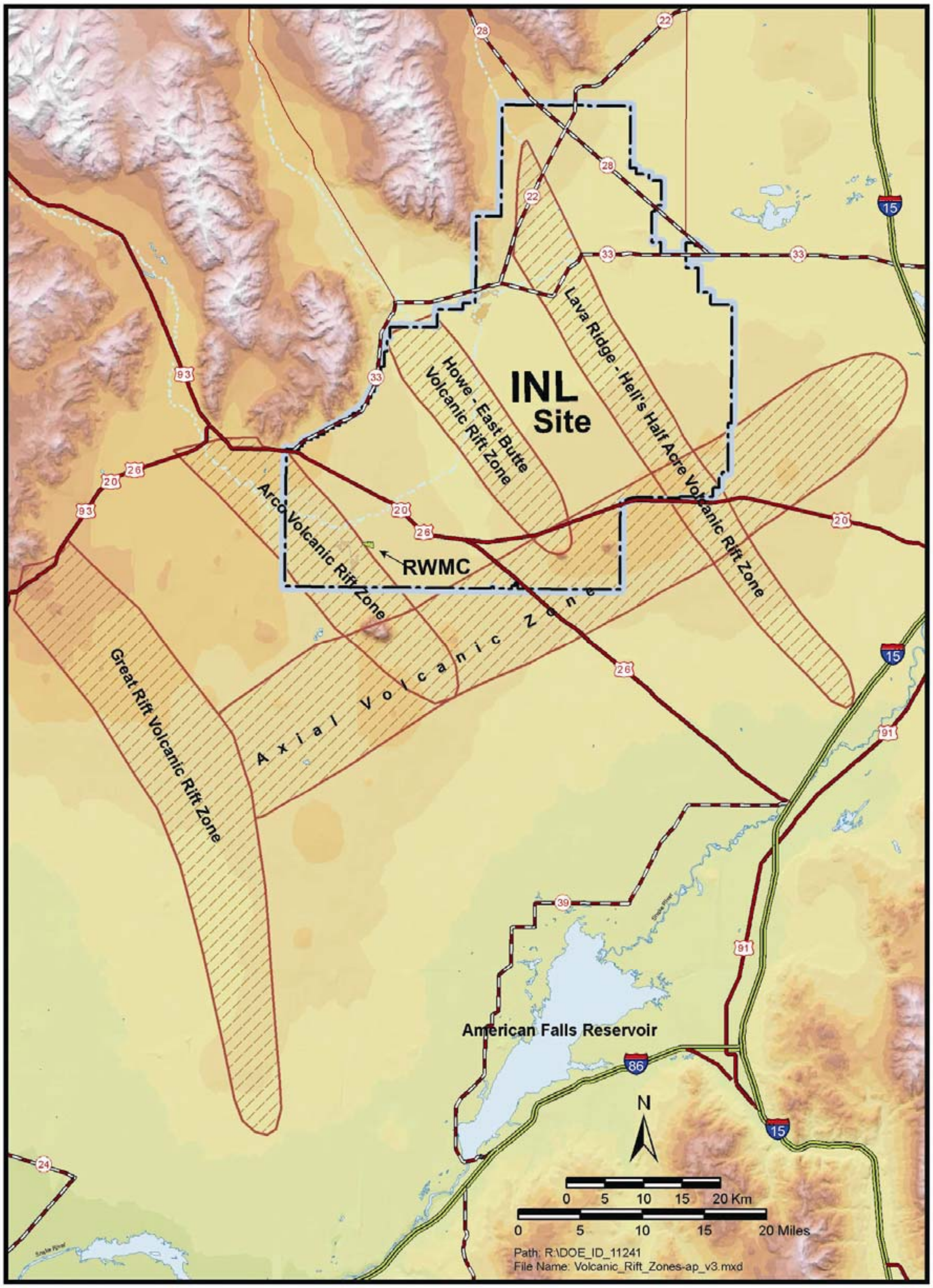



Figure 2-7. Volcanic rift zones (modified from Smith, Jackson, and Hackett 2006).

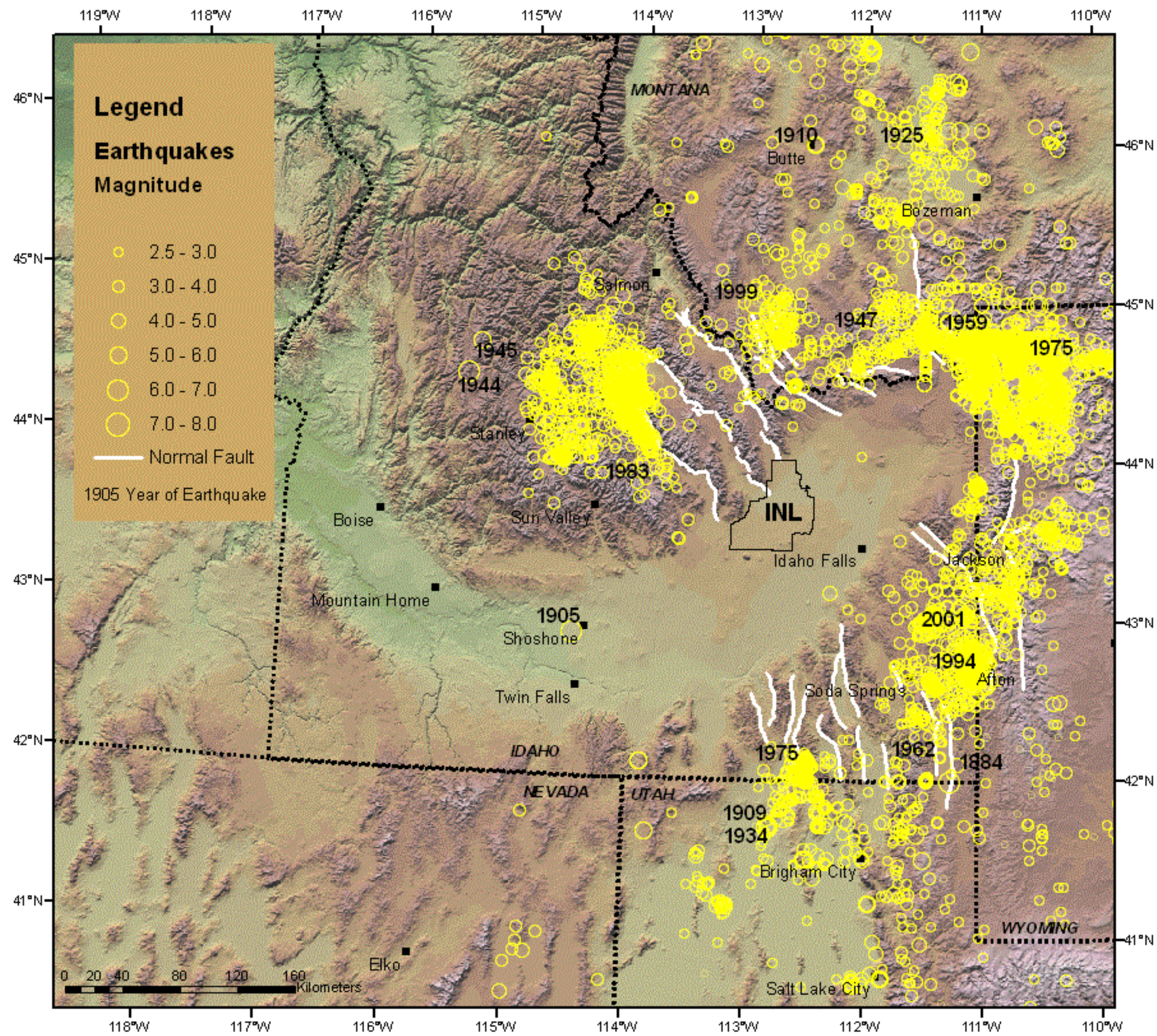



Figure 2-8. Earthquake epicenters compiled from regional seismic networks for magnitudes greater than 2.5 occurring from 1872 to 2004.

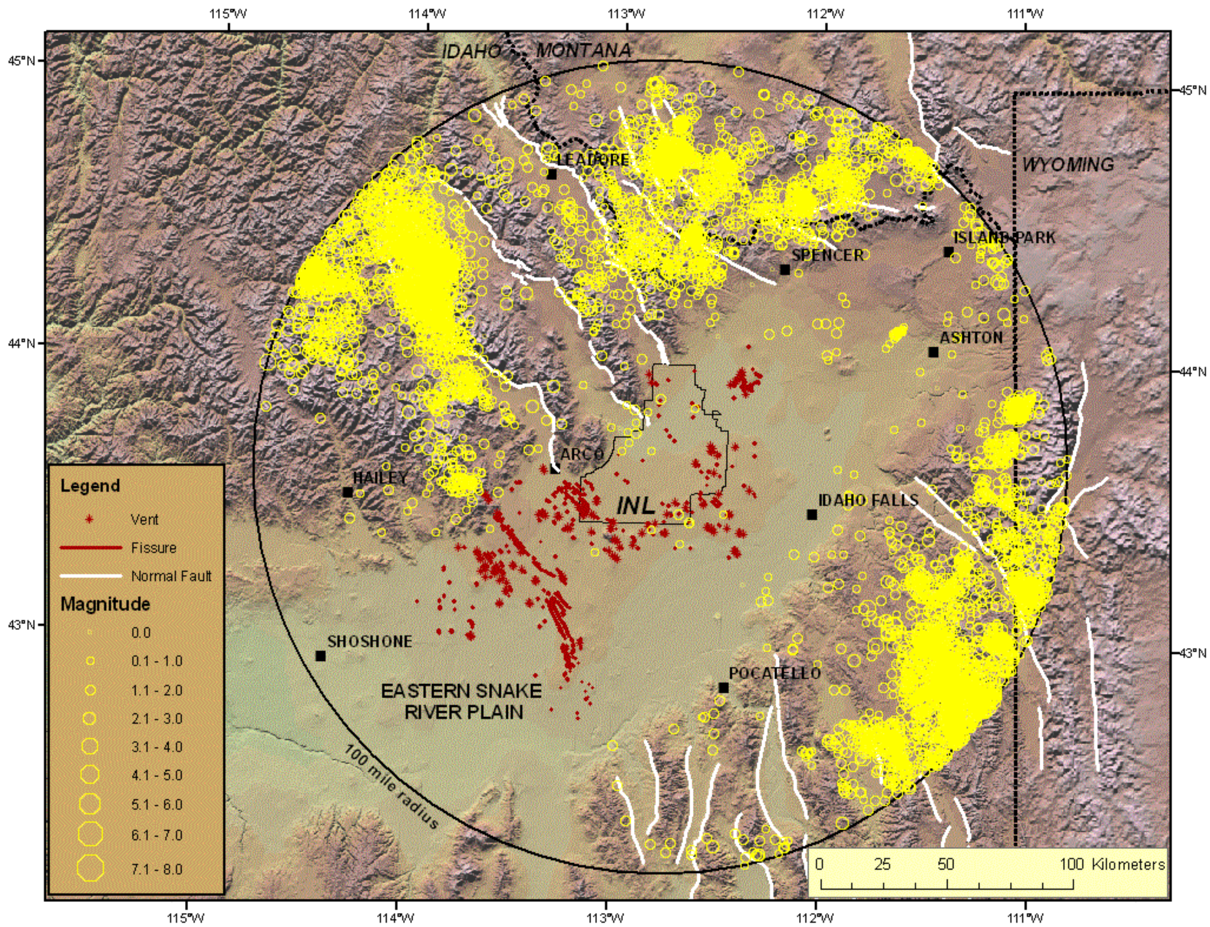



Figure 2-9. Epicenters of earthquakes occurring from 1972 to 2004 compiled by the Idaho National Laboratory Seismic Monitoring Program.

The largest historic earthquake in the region occurred on August 17, 1959, at Hebgen Lake, Montana, located approximately 193 km (120 mi) northeast of the INL Site (see Figure 2-8). The event had a surface-wave magnitude of 7.5 and was felt at the INL Site, but caused no damage there.

Because the seismically active Intermountain and Centennial seismic belts surround the eastern Snake River Plain and several Quaternary faults are located near the western boundary of the INL Site, seismic-hazard assessments were completed for all facility areas at the INL Site (INEL 1996; INEEL 2000; Payne et al. 2002). Seismic-hazard evaluations were conducted using a probabilistic methodology that incorporates the most up-to-date region- and site-specific geologic, seismologic, and geotechnical information for the INL Site. These assessments quantitatively estimated peak ground motions that INL Site facilities may experience from nearby large-magnitude earthquakes. The site-specific geological, seismological, and geotechnical data used in INL Site ground-motion evaluations were provided to U.S. Geological Survey (USGS) personnel, who also used these data to develop national seismic hazard maps. The seismic design levels in the form of peak ground accelerations are obtained from the “USGS National Seismic Hazard Maps” (USGS 2005a) for the *International Building Code* (ICC 2000), which is currently used for nonnuclear facilities at RWMC.

### 2.2.6 Volcanology

The INL Site is located in a region of Pleistocene and Holocene volcanic activity typically characterized by nonviolent, effusive basalt lava flows (Hackett and Smith 1992). Explosive rhyolite volcanism occurred beneath the INL Site 4 to 7 million years ago, forming calderas now buried beneath basalt lava flows. In the region immediately surrounding the INL Site, the youngest lava flow erupted about 4,100 years ago from Hell's Half Acre Lava Flow southeast of the INL Site. Within INL Site boundaries, the most recent lava flow—the Cerro Grande flow—occurred 13,000 years ago, near the southern boundary (Hackett, Pelton, and Brockway 1986).

Renewed explosive rhyolite volcanism at the INL Site is very unlikely. Geological and geochronological data indicate an eastward progression of silicic volcanism. The mantle plume or hotspot assumed responsible for the volcanism now lies beneath Yellowstone National Park. Past patterns of volcanism suggest that future volcanism at the INL Site within the next 1,000 to 10,000 years is very improbable (INEL 1990), and the two most likely sources of future basalt flows on the INL Site are the Arco-Big Southern Butte and Lava Ridge-Hell's Half Acre rift zones (see Figure 2-7).

Most of the INL Site is underlain by a 0 to 1-km (0 to 0.6-mi) -thick sequence of Tertiary and Quaternary basalt lava flows and interbedded sediments. Based on drill-hole information, regional mapping along the margins of the eastern Snake River Plain, and geophysical information, the basalt and sediment sequence is underlain by an older section (up to several kilometers thick) of late Tertiary rhyolitic volcanic rock. These two volcanic sequences are a consequence of the passage of the Yellowstone mantle plume (hotspot) through the INL Site area of the eastern Snake River Plain in late Tertiary. The Tertiary rhyolitic volcanic rocks were erupted 6.5 to 4.3 million years ago when the hotspot resided beneath the INL Site area (Pierce and Morgan 1992). These volcanic rocks are composed mostly of ash-flow tuffs erupted during large, violent explosive episodes and large rhyolitic lava flows. These rocks are analogous to the ash flow tuffs and lava flows that erupted from calderas in the Yellowstone Plateau from 2.0 to 0.6 million years ago.

These types of large-scale explosive eruptions can occur only directly over the position of the mantle hotspot because large inputs of heat into the lower and middle crust are required to generate such large volumes of rhyolitic magma. Because the hotspot is now situated beneath Yellowstone National Park, recurrence of this type of volcanic activity in the INL Site area is not possible (INEL 1990). Regional extension of the crust and residual heat in the upper mantle, after passage of the hotspot, have resulted in basaltic magmas that have risen to the surface and erupted onto the subsiding eastern Snake River Plain. Basaltic eruptions in the INL Site area began about 4 million years ago, soon after passage of the hotspot, and have occurred as recently as 2,100 years ago along the Great Rift.

Basalt vents on the eastern Snake River Plain include broad, low-relief shield volcanoes, small spatter cones, and spatter ramparts along eruptive fissures. Lava fields related to single vents range in surface area from 2 to 400 $km^2$ (0.7 to 154 $mi^2$) and in volume from 0.05 to 7 $km^3$ (0.01 to 1.7 $mi^3$) (Kuntz, Covington, and Schorr 1992). Volcanic vents are not randomly distributed on the plain, but are concentrated in northwest-trending linear zones known as volcanic rift zones (see Figure 2-10).

In addition, vents are concentrated in a northeast-trending zone, known as the Axial Volcanic Zone, along the central axis of the eastern Snake River Plain. The Axial Volcanic Zone is a constructional highland caused by more voluminous magma output along the axis of the plain.

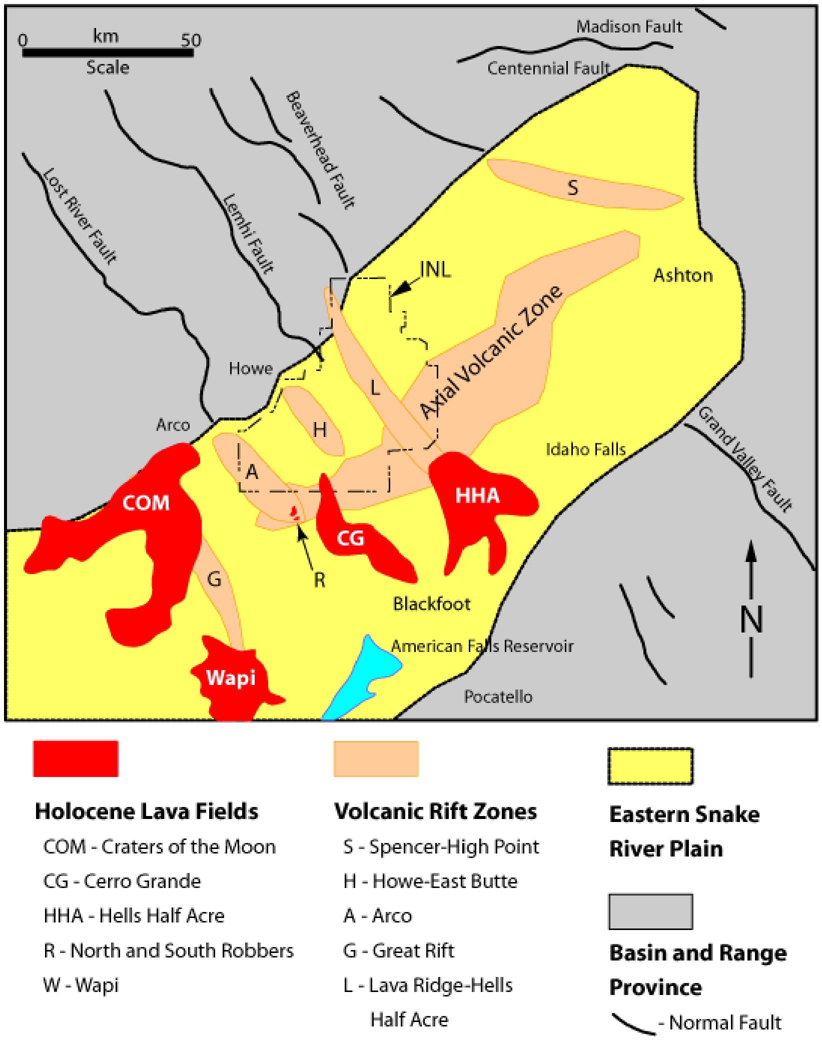



Figure 2-10. Volcanic rift zones and Holocene basalt lava fields.

For volcanic areas, such as the eastern Snake River Plain, with no historical volcanism and an incomplete chronological record of prehistoric volcanism, assessments of potential volcanic hazards and volcanic risk are based on interpretation of the long-term geologic record and on documented effects of historical eruptions in analogous regions such as Iceland and Hawaii. The most significant volcanic hazard to the INL Site is inundation or burning of facilities by basaltic lava flows from volcanic rift zones. A significant related hazard would be disruption of facilities resulting from ground deformation accompanying magma intrusion along volcanic rift zones, including opening of fissures, normal faulting, and broad regional tilting and uplift within several miles of vents. Other, less-significant basaltic hazards would include volcanic-gas emission and disruption of groundwater flow paths.

Based on radiometric age determinations of basalt lava flows, the Arco Volcanic Rift Zone north of Big Southern Butte was active between 600 and 100,000 years ago (Kuntz, Covington, and Schorr 1992). The Cerro Grande and North and South Robbers flows (i.e., 10,500 to 12,000 years ago) near Big Southern Butte occur at the intersection of the Arco Volcanic Rift Zone and the Axial Volcanic Zone. Except for volcanism along the Great Rift, all Holocene volcanic fields of the eastern Snake River Plain occur along the Axial Volcanic Zone (see Figure 2-10). Volcanism in the plain is more likely to recur along the Great Rift or the Axial Volcanic Zone (Hackett, Smith, and Khericha 2002).

Available geologic map data and geochronometry of basalt lava flows at the INL Site suggest minimum (i.e., most conservative) volcanic-recurrence intervals of $10^{-4}$ to $10^{-5}$/year for the Axial Volcanic Zone and the Arco and Lava Ridge-Hell's Half Acre volcanic rift zones. Therefore, probabilistic risk of basalt lava inundation or intrusion-related ground disturbance is estimated to be less than $10^{-5}$/year (i.e., 1 chance in 100,000/year) for the southern INL Site. The probability of significant impact from volcanic phenomena (e.g., growth of new rhyolite domes on the eastern Snake River Plain or tephra falls thicker than 8 cm [3 in.] from non-Snake River Plain vents) is estimated to be less than $10^{-5}$/year because of the combined effects of great distance, infrequency, low volume, and topographic or atmospheric barriers to dispersal of tephra on the INL Site.

The Volcanism Working Group (INEL 1990) estimated the probability of inundation of RWMC by basalt flows to be much less than $10^{-5}$ (i.e., 1 chance in 100,000) per year. The chief volcanic hazard at RWMC is inundation by lava flows from source vents outside RWMC boundaries (INEL 1990). In the unlikely event that lava flows should inundate RWMC, the principal effect on surficial and buried waste would be localized heating to 300°C (572°F) to a depth of less than 3 m (9.8 ft). Other potential effects (i.e., fissuring and gas corrosion) are even more unlikely because RWMC lies outside known volcanic rift zones (Hackett, Anders, and Walter 1994).

### 2.2.7 Surface Soil

Soil at the INL Site is derived from Cenozoic felsic volcanic and Paleozoic sedimentary rock from nearby mountains. Soil in the northern portion of the INL Site is generally composed of fine-grained lacustrine and eolian deposits of unconsolidated clay, silt, and sand. Typically, soil in the southern portion of the INL Site is shallow and consists of fine-grained eolian soil deposits with some fluvial gravels and gravelly sand (INEL 1988). Across the INL Site, measured surficial soil thicknesses range from zero at basalt outcrops east of the Idaho Nuclear Technology and Engineering Center (INTEC) to 95 m (313 ft) near the Big Lost River sinks southwest of Test Area North (Anderson, Liszewski, and Ackerman 1996).

Soil in the RWMC area was formed from several types of soil-genesis cycles, including loess deposition, leaching of calcium carbonate, accumulation of clay, and erosion. The RWMC area is topographically associated with Big Lost River and Big Southern Butte fluvial systems and contains pebble lag within the area of boulder trains, indicating at least one Holocene-age flood from the Big Lost River. However, evidence of erosion by these systems during the last 10,000 years, following the end of the Pinedale glaciation, is not evident.

Physical, chemical, and mineralogical characteristics of RWMC area soil are detailed in Dechert, McDaniel, and Falen (1994) and McDaniel (1991). Generally, soil mantling the landscape surrounding RWMC was deposited as loess during the Pinedale glaciation and mixed with eolian sand and slope wash in lower areas of the basin. Soil from RWMC typically has high clay content (approximately 36%) and high silt content (approximately 56%) (Chatwin et al. 1992). Generally, soil has moderate water-holding capacity, though some areas of RWMC have shallow soil with low water-holding capacity (Bowman et al. 1984). Some RWMC soil also may be derived from historic stream deposits from the Big Lost River.

Undisturbed surficial deposits within the RWMC area range in thickness from 0.6 to 7.0 m (2 to 23 ft) (Anderson, Liszewski, and Ackerman 1996). Irregularities in soil thickness generally reflect the undulating surface of underlying basalt flows. Many physical features are common within the soil stratigraphy of the RWMC area (e.g., pebble layers, freeze-thaw textures, loess deposition, and platy caliche horizons). Surface soil in RWMC has been significantly disturbed and recontoured, with additional backfill added for subsidence and run-off control.

### 2.2.8 Surface Hydrology

Surface hydrology at the INL Site includes water from three streams that flow intermittently onto the INL Site and from local run-off caused by precipitation and snowmelt. Most of the INL Site is located in Pioneer Basin, into which three streams drain: Big Lost River, Little Lost River, and Birch Creek. These streams receive water from mountain watersheds located north and northwest of the INL Site. Pioneer Basin has no outlet; thus, water flowing onto the INL Site either evaporates or infiltrates into the ground (Irving 1993). Irrigation diversions and infiltration losses often deplete stream flows before reaching INL Site boundaries. Flow onto INL Site boundaries occurs when spring run-off exceeds irrigation demands and infiltration losses.

The Big Lost River is the major surface water feature on the INL Site, entering from the west and terminating at the Big Lost River sinks in the northwestern part of the INL Site where water either evaporates or infiltrates into the Snake River Plain Aquifer. Waters of the Big Lost River are impounded and regulated by Mackay Dam, which is located approximately 6 km (4 mi) north of Mackay, Idaho. On leaving the dam, waters of the Big Lost River flow southeastward past Arco and onto the eastern Snake River Plain. Flow in the Big Lost River that actually reaches the INL Site is either diverted at the INL Site diversion dam to spreading areas southwest of RWMC, or flows northward across the INL Site in a shallow channel to its terminus at Lost River Sinks. At this point, flow is lost to evaporation and infiltration (Irving 1993). Locations of the surface water features and spreading areas are illustrated in Figure 2-11.

A diversion system was constructed on the Big Lost River in 1958 to protect INL Site facilities from potential flooding. The system consists of a diversion dam, gated culverts, and a channel, which diverts high flow to Spreading Areas A, B, C, and D west and southwest of the SDA (see Figure 2-2). At the diversion dam, the main channel of the Big Lost River flows through two 1.8-m (6-ft) -diameter gated culverts and continues downstream. During periods of high run-off, all flow greater than the 25.5-m$^3$/second (900-ft$^3$/second) culvert capacity is diverted to Spreading Area A, then sequentially to remaining Spreading Areas B, C, and D (Lamke 1969). The diversion channel can carry 142 m$^3$/second (5,000 ft$^3$/second) from the Big Lost River channel into the spreading areas, assuming 0.9 m (3 ft) of freeboard (Bennett 1986), which provides a safe holding capacity for the INL diversion dam. The capacity of the spreading areas is 11,514,000 m$^3$ (58,000 acre-ft) at an elevation of 1,539 m (5,050 ft) (McKinney 1985). An overflow weir in Spreading Area D allows water to drain southwest off the INL Site. Run-off from the Big Lost River has never been sufficient to exceed the capacity of the spreading area and overflow the weir. The last recorded flow to the spreading areas from the Big Lost River was in May 2000. Figure 2-12 shows the Big Lost River daily mean stream flow to the spreading areas at the INL Site diversion dam from 1984 through September 2005.

Because of above-average mountain snow pack in 1995, water in the Big Lost River was sufficient during the summer of 1995 to flow to the spreading areas and sinks and to the playas south of Test Area North. Flow during this time ranged from 13.3 m$^3$/second (469 ft$^3$/second) near RWMC in mid-July to 0.8 m$^3$/second (29 ft$^3$/second) in early August (Becker et al. 1996). The Big Lost River flowed intermittently for much of the period between 1995 and 2000 (measured at the USGS gauging station approximately 8 km [5 mi] west of the INL Site boundary), and then again in June and July 2005 (USGS 2005b).

The Little Lost River drains from the slopes of the Lemhi and Lost River Ranges. Flow in the Little Lost River is diverted for irrigation north of Howe, Idaho, and does not normally reach the INL Site. The Little Lost River has negligible potential for flooding on the INL Site (Kjelstrom and Berenbrock 1996).

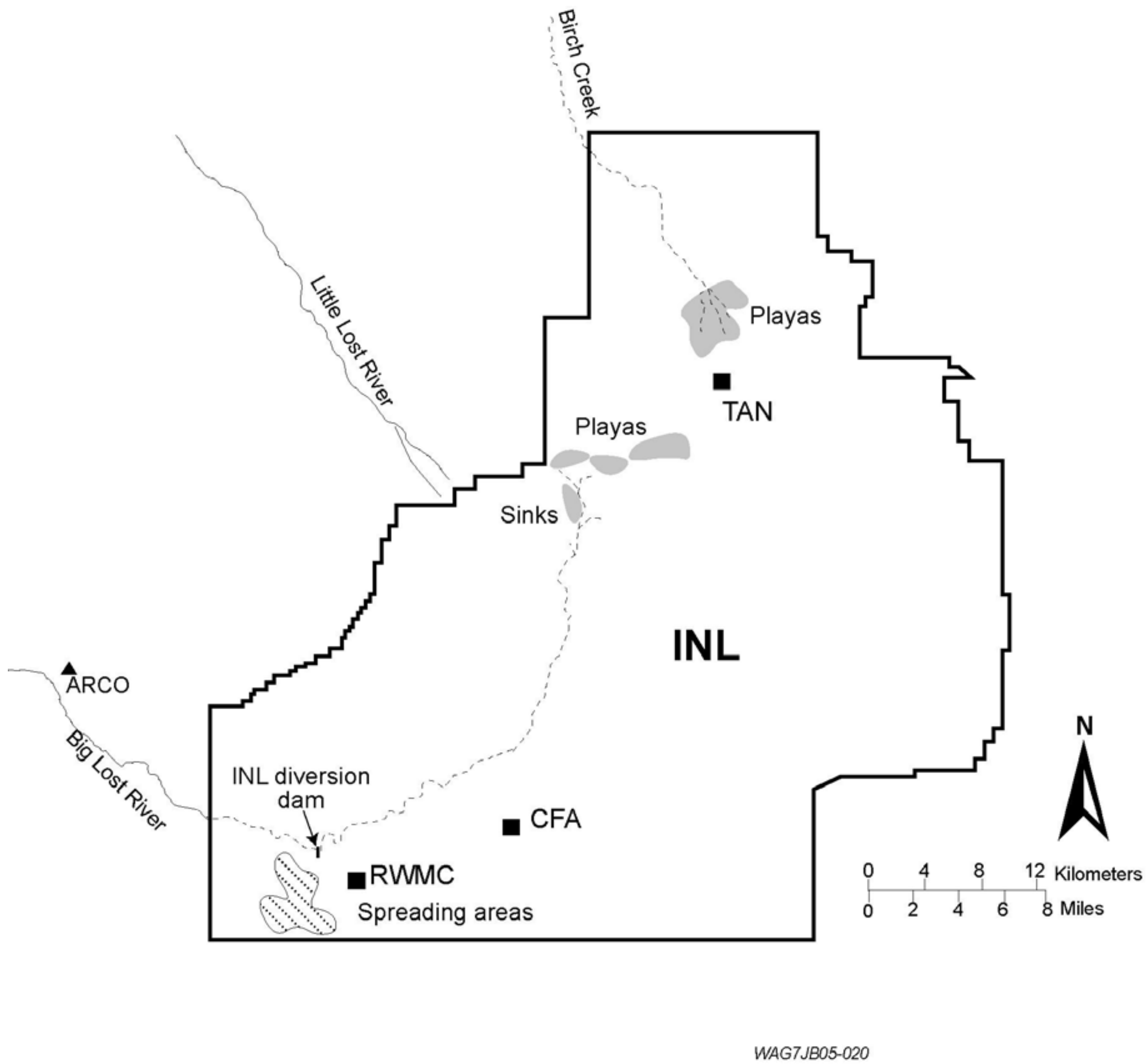



Figure 2-11. Surface water features of the Idaho National Laboratory Site.

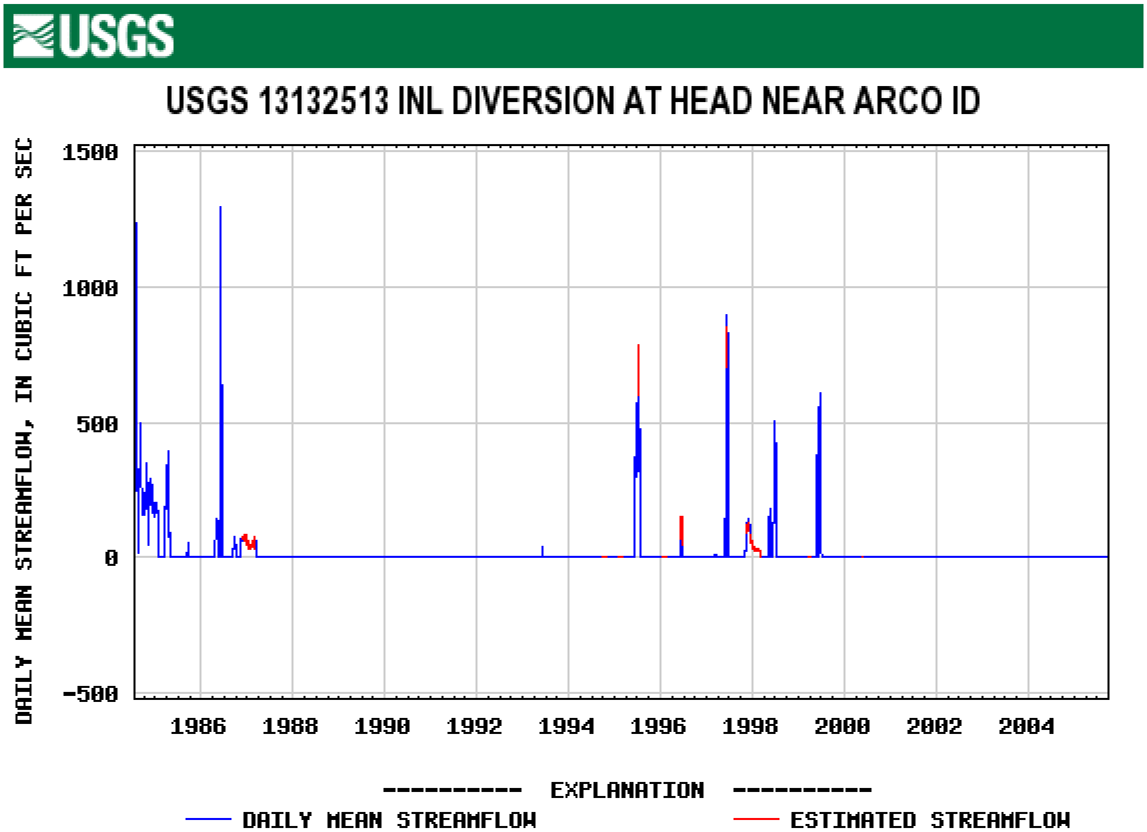



Figure 2-12. Daily mean stream flow to the spreading areas at the Idaho National Laboratory Site diversion dam on the Big Lost River from September 1984 to 2005 (USGS 2005b).

Sources for Birch Creek comprise springs below Gilmore Summit in the Beaverhead Mountains and drainage from the surrounding basin. Water from Birch Creek flows southeast between the Lemhi and Bitterroot Ranges and is diverted north of the INL Site for irrigation and hydropower during summer. During winter, water not used for irrigation is returned to a channel constructed 6 km (4 mi) north of Test Area North, where water infiltrates into channel gravels, recharging the aquifer (Irving 1993). Surface water features of the INL Site are illustrated in Figure 2-11.

The RWMC is located within a natural topographic depression with no permanent surface water features (see Figure 2-3). However, the local basin tends to hold precipitation and to collect additional run-off from surrounding slopes. Surface water within Waste Area Group 7 and the surrounding local area does not reach the Big Lost River (Keck 1995). Surface water eventually either evaporates or infiltrates to the vadose zone and the underlying aquifer.

***2.2.8.1 Big Lost River 100-Year Floodplain—***The RWMC is located outside the 100-year floodplain of the Big Lost River. The Big Lost River, 3.2 km (2 mi) north of the SDA, is at an elevation of 9 to 12 m (30 to 40 ft) higher than the SDA (see Figure 2-3). However, the Big Lost River does not pose a flood threat to the SDA. The river is topographically isolated from the SDA and flows northeast away from the facility to its termination in the playas. This position is supported by a recent study conducted by the Bureau of Reclamation (Ostenaa and O'Connell 2005) and the flood-routing analysis of a hypothetical failure of Mackay Dam resulting from hydrologic and seismic events (Koslow and Van Haaften 1986). The studies indicate that severe flooding from the Big Lost River would not inundate RWMC. An evaluation of the RWMC geomorphic setting (based on soil profiles taken along the Big Lost River and used to develop a late Quaternary soil chronosequence) indicates that RWMC is sited on geomorphic surfaces that are well over 10,000 years old. This evaluation suggests that the hazard of significant flooding of this area by the Big Lost River is low under natural channel conditions (Ostenaa et al. 1999). The past 10,000 years (i.e., the Holocene epoch, which followed the last glacial episode) was a period of soil formation and limited erosion in the small valley in which RWMC is located. Substantial soil layers from about 20,000 to 120,000 years old remain apparently undisturbed, which indicates that older soil did not erode significantly (Hackett et al. 1995). Climate changes during the approximate 10,000 years after the last glacial episode have had little effect on the soil landscape within the RWMC basin. Therefore, if climate fluctuations are within historical limits, the same may be true for the next 10,000 years.

***2.2.8.2 Local RWMC Run-on and Run-off—***Historically, the SDA has been flooded by local basin run-off at least three times because of a combination of snowmelt, rain, and warm winds (see Figure 2-13). Dikes and drainage channels were constructed around the perimeter of the SDA in 1962 in response to the first flooding event. The height of the dike was increased, and the drainage channel around the perimeter was enlarged following a second flood in 1969. The dike was breached by accumulated snowmelt in 1982, resulting in a third inundation of open pits within the SDA. Additional flood-control improvements included (1) increasing the height and width of the dike, (2) deepening and widening the drainage channel, and (3) contouring to eliminate formation of surface ponds and to route run-off to the drainage channel. Local basin run-off from surrounding slopes is now prevented from entering the SDA by the perimeter drainage channel and dike surrounding the facility. Run-off from inside the SDA is directed to the perimeter drainage channel where it exits the disposal area.

As long as the drainage system is maintained, the existing SDA peripheral drainage ditch and the main discharge channel along Adams Boulevard adequately protect the SDA from the 25- and 100-year combined rain and snow events (Mitchel et al. 2001). A statistical analysis of meteorological data from CFA from 1950 through 1995 estimates 4.3 cm (1.7 in.) of precipitation for a 25-year, 24-hour storm event and 5.6 cm (2.2 in.) of precipitation for a 100-year, 24-hour storm event (Sagendorf 1996). A hydrological evaluation of the RWMC drainage system was performed to determine if it is adequate for handling run-on and run-off from the 25-year and 100-year, 24-hour storm events (Mitchell et al. 2001). The study concludes the RWMC drainage system could safely carry run-on and run-off from these two storm events without "washing out" or ponding water in the SDA.

### 2.2.9 Subsurface Hydrology

Subsurface hydrology at the INL Site has three components: the vadose zone, perched water, and the aquifer. The vadose zone, also referred to as the unsaturated zone, extends from land surface down to the aquifer water table. Water content of geologic materials in the vadose zone is commonly less than saturation, and water is held under negative pressure. Perched water in the subsurface forms as discontinuous saturated lenses, with unsaturated conditions existing both above and below the lenses. Bodies of perched water are formed by vertical, and to a lesser extent, lateral migration of water moving away from a source until an impeding sedimentary layer is encountered. The aquifer, also referred to as the saturated zone, occurs at various depths beneath the eastern Snake River Plain. Approximately 9% of the aquifer lies beneath the INL Site (see Figure 2-1) (DOE-ID 1995). Depths to the water table range from approximately 61 m (200 ft) in the northern part of the INL Site to greater than 274 m (900 ft) in the southern part (Irving 1993).

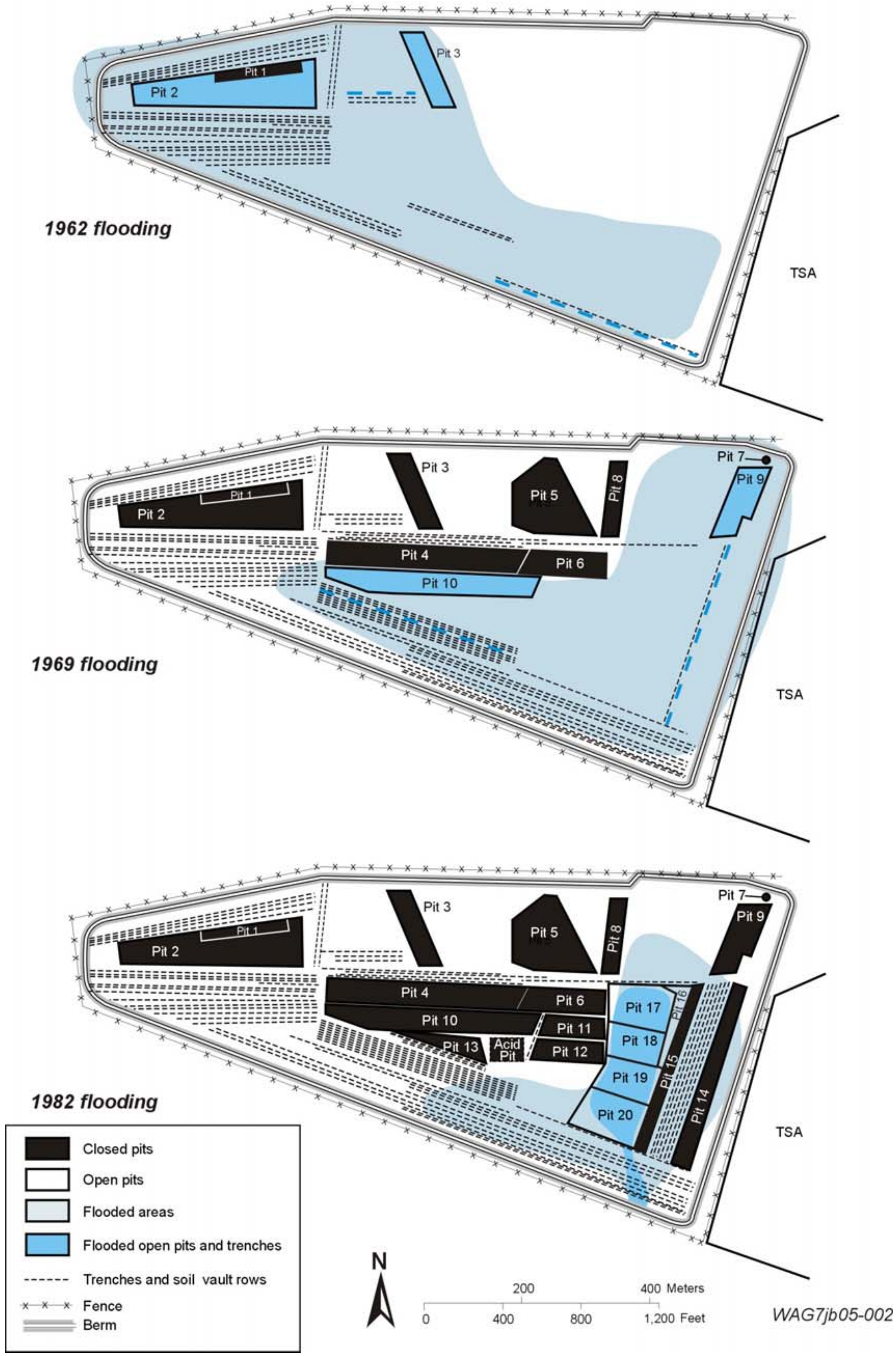



Figure 2-13. Historical floods in the Subsurface Disposal Area.

Description of the subsurface geology and hydrology is based on interpretation of data obtained from drilling and monitoring wells. Some wells are limited to the vadose zone, while others extend into the aquifer. Table 2-1 lists formal names of wells and boreholes in the vicinity of RWMC, along with short names or aliases for many of the wells. Aliases are commonly used in text and illustrations throughout this document.

Table 2-1. Names and common aliases for wells in the vicinity of the Radioactive Waste Management Complex.

| Well Name | Common Alias | Well Name | Common Alias |
|---|---|---|---|
| 76-1 | 76-1 | NA-89-2 | NA89-2 |
| 76-2 | 76-2 | NA-89-3 | NA89-3 |
| 76-3 | 76-3 | PA-01 | PA01 |
| 76-4 | 76-4 | PA-02 | PA02 |
| 76-4A | 76-4A | Rifle Range Well | Rifle Range |
| 76-5 | 76-5 | T-23 | T23 |
| 76-6 | 76-6 | TH-02 | TH02 |
| 77-1 | 77-1 | TH-04 | TH04 |
| 77-2 | 77-2 | TH-05 | TH05 |
| 78-1 | 78-1 | TW-1 | TW-1 |
| 78-2 | 78-2 | USGS-009 | USGS-9 |
| 78-3 | 78-3 | USGS-086 | USGS-86 |
| 78-4 | 78-4 | USGS-087 | USGS-87 |
| 78-5 | 78-5 | USGS-088 | USGS-88 |
| 79-1 | 79-1 | USGS-089 | USGS-89 |
| 79-2 | 79-2 | USGS-090 | USGS-90 |
| 79-3 | 79-3 | USGS-091 | USGS-91 |
| 88-01D | 88-01D | USGS-092 | USGS-92 |
| 88-02D | 88-02D | USGS-093 | USGS-93 |
| 89-01D | 89-01D | USGS-094 | USGS-94 |
| 89-02D | 89-02D | USGS-095 | USGS-95 |
| USGS-093A | USGS-93A | USGS-096 | USGS-96 |
| USGS-096B | USGS-96B | USGS-105 | USGS-105 |
| D-02 | DO-2 | USGS-106 | USGS-106 |
| D-06 | D06 | USGS-108 | USGS-108 |
| D-06 | DO-6 | USGS-109 | USGS-109 |
| D-06A | D-06A | USGS-117 | USGS-117 |
| D-06A | DO-6A | USGS-118 | USGS-118 |
| D-10 | D-10 | USGS-119 | USGS-119 |
| D-15 | D-15 | USGS-120 | USGS-120 |
| EBR-I | EBR-I | VZT-01 | VZT-1 |
| Highway 3 | HWY-3 | W-03 | W03 |
| NA-89-1 | NA89-1 | W-04 | W04 |

Table 2-1. (continued).

| Well Name | Common Alias | Well Name | Common Alias |
|---|---|---|---|
| W-05 | W05 | RWMC-1815 | IE-6 |
| W-06 | W06 | RWMC-1816 | DE-6 |
| W-08 | W08 | RWMC-1817 | SE-7 |
| W-09 | W09 | RWMC-1818 | IE-7 |
| W-13 | W13 | RWMC-1819 | DE-7 |
| W-17 | W17 | RWMC-1820 | SE-8 |
| W-20 | W20 | RWMC-1821 | IE-8 |
| W-23 | W23 | RWMC-1822 | DE-8 |
| W-25 | W25 | RWMC-GAS-V-072 | 1V |
| WWW1 | WWW#1 | RWMC-GAS-V-074 | 3V |
| WWW2 | WWW#2 | RWMC-GAS-V-075 | 4V |
| RWMC | RWMC | RWMC-GAS-V-076 | 5V |
| M1SA | M1SA | RWMC-GAS-V-077 | 6V |
| M3S | M3S | RWMC-GAS-V-078 | 7V |
| M4D | M4D | RWMC-GAS-V-079 | 8V |
| M6S | M6S | RWMC-GAS-V-080 | 9V |
| M7S | M7S | RWMC-GAS-V-081 | 10V |
| M10S | M10S | RWMC-MON-A-065 | OW-1 |
| C1 | C-1 | RWMC-MON-A-066 | OW-2 |
| C1A | C-1A | RWMC-OBS-A-084 | LSIT Test Well |
| 9301 | 93-01 | RWMC-NEU-S-094 | NAT-1 |
| 9302 | 93-02 | RWMC-NEU-S-095 | NAT-2 |
| W-02 | W02 | RWMC-NEU-S-096 | NAT-3 |
| W-02 | W-02 | RWMC-NEU-S-097 | NAT-4 |
| RWMC-MON-A-013 | A11A31 | RWMC-NEU-S-098 | NAT-5 |
| RWMC-VVE-V-068 | 2E | RWMC-NEU-S-099 | NAT-6 |
| RWMC-VVE-V-069 | 3E | RWMC-NEU-S-100 | NAT-7 |
| RWMC-GAS-V-073 | 2V | RWMC-NEU-S-101 | NAT-8 |
| RWMC-VVE-V-067 | 1E | RWMC-NEU-S-102 | NAT-9 |
| RWMC-VVE-V-071 | 5E | RWMC-NEU-S-103 | NAT-10 |
| RWMC-VVE-V-070 | 4E | RWMC-NEU-S-104 | NAT-11 |
| RWMC-VVE-V-205 | 6E | RWMC-NEU-S-105 | NAT-12 |
| RWMC-VVE-V-204 | 7E | RWMC-NEU-S-106 | NAT-13 |
| RWMC-VVE-V-163 | DE-1 | RWMC-NEU-S-107 | NAT-14 |
| RWMC-1808 | SE-3 | RWMC-NEU-S-108 | NAT-15 |
| RWMC-1809 | IE-3 | RWMC-NEU-S-109 | NAT-16 |
| RWMC-1810 | DE-3 | RWMC-NEU-S-110 | NAT-17 |
| RWMC-1812 | IE-4 | RWMC-SCI-S-115 | LYS-1 |
| RWMC-1813 | DE-4 | SOUTH-MON-A-001 | M11S |
| RWMC-1814 | SE-6 | SOUTH-MON-A-002 | M12S |

Table 2-1. (continued).

| Well Name | Common Alias | Well Name | Common Alias |
|---|---|---|---|
| SOUTH-MON-A-003 | M13S | SOUTH-MON-A-009 | M15S |
| SOUTH-MON-A-004 | M14S | SOUTH-GAS-V-005 | VVE-11 |
| RWMC-SCI-V-153 | I-1S | SOUTH-GAS-V-007 | VVE-13 |
| RWMC-SCI-V-160 | I-1D | SOUTH-GAS-V-008 | VVE-14 |
| RWMC-SCI-V-154 | I-2S | SOUTH-1835 | S1835 |
| RWMC-SCI-V-155 | I-2D | SOUTH-1835 | S1835 |
| RWMC-SCI-V-156 | I-3S | SOUTH-1898 | S1898 |
| RWMC-SCI-V-157 | I-3D | VVE 1 | VVE 1 |
| RWMC-SCI-V-158 | I-4S | VVE 3 | VVE 3 |
| RWMC-SCI-V-159 | I-4D | VVE 4 | VVE 4 |
| RWMC-SCI-V-161 | I-5S | VVE 6 | VVE 6 |
| RWMC-SCI-V-161 | I-5S/D | VVE 7 | VVE 7 |
| RWMC-MON-A-162 | M17S | VVE 10 | VVE 10 |
| RWMC-SCI-V-203 | O-8 | — | 98-1 |
| SOUTH-SCI-V-014 | O-6 | — | 98-2 |
| SOUTH-SCI-V-011 | O-1 | — | 98-3 |
| SOUTH-SCI-V-012 | O-2 | — | 98-4 |
| SOUTH-SCI-V-013 | O-3 | — | 98-5 |
| SOUTH-SCI-V-018 | O-4 | PA-03 | PA-03 |
| SOUTH-SCI-V-015 | O-5 | PA-04 | PA-04 |
| SOUTH-SCI-V-016 | O-7 | — | — |
| SOUTH-MON-A-010 | M16S | — | — |

***2.2.9.1 Vadose Zone.*** The vadose zone, defined as the unsaturated region between land surface and an underlying aquifer, or the water table, is a particularly important component of the hydraulic system at the INL Site for three primary reasons:

- A thick vadose zone protects groundwater by acting as a filter and preventing many contaminants from reaching the aquifer

- The vadose zone acts as a buffer by providing storage for large volumes of liquid or dissolved contaminants that have spilled on the ground, migrated from disposal pits and ponds, or have otherwise been released to the environment

- Transport of contaminants through the thick, mostly unsaturated materials can be slow if low infiltration conditions prevail.

An extensive vadose zone exists at the INL Site, ranging in thickness from 61 m (200 ft) in the north at Test Area North to greater than 274 m (900 ft) near the southern INL Site boundary. The vadose zone consists of sacrificial sediment, relatively thin horizontal basalt flows, and occasional interbedded sediment (Irving 1993). Surfacial sediment in the vadose zone includes clay, silt, sand, and some gravel. Thick surficial deposits of clay and silt are found in the northern part of the INL Site, but the deposits decrease in thickness toward the south, where some basalt is exposed at the topographic surface.

Approximately 90% of the vadose zone is composed of thick sequences of interfingering basalt flows. These sequences are characterized by large void spaces resulting from fissures, rubble zones, lava tubes, undulating basalt-flow surfaces, and fractures. Sedimentary interbeds in the vadose zone consist of sand, silt, and clay and are generally thin and discontinuous. Sediment may be compacted because of subsequent overburden pressures. Under unsaturated conditions with limited water, flow will move preferentially through small openings in sediment or basalt, avoiding large openings.

The subsurface of RWMC comprises a thin (i.e., 0 to 7 m [0 to 23 ft]) cover of loess resting on a thick sequence of fractured basalt intercalated with thin sedimentary interbeds (see Figures 2-5 and 2-6). The Snake River Plain Aquifer underlies RWMC at a depth of approximately 177 m (580 ft). The RWMC lies within a natural topographic depression. Major sources of water at the surface are direct precipitation and run-off from snowmelt, which concentrates water in topographically low areas within the SDA. This occurred on a large scale in 1962, 1969, and 1982 (see Figure 2-13) when rapid snowmelts, combined with heavy rain, flooded pits and trenches in the SDA (Barraclough et al. 1976; Bargelt et al. 1992). Local run-off from late winter and early spring snowmelt has the greatest potential for infiltration because these events occur when evapotranspiration rates are low. Disturbed soils and sparse vegetation may also contribute to increased infiltration within the SDA. Based on vadose zone instrumentation in the surficial sediment, Laney et al. (1988), McElroy (1990), and Martian and Magnuson (1994) conclude that surface infiltration within the SDA is highly nonuniform and is concentrated in surface depressions. If spring thaw occurs over frozen ground, most melt water is diverted to topographically low areas, increasing infiltration in low areas while reducing infiltration in higher areas. Intense spring and summer rainstorms also can have the same effect.

During localized recharge events, wetting fronts move through surficial sediment and into underlying basalt. Continued downward movement through the basalt is assumed to occur primarily through open or sediment-filled fractures or joints rather than through the basalt matrix. Rapid infiltration through fractured basalt or basalt flow rubble zones can occur. In 1999, recharge was monitored to the 17.3-m (57-ft) depth at SDA Well 76-5 (Hubbell et al. 2002). The average advance of the wetting front varied as it moved downward, from 0.1 m/day (0.33 ft/day) at the 11.6-m (38-ft) depth to 0.04 m/day (0.13 ft/day) at the 17.3-m (57-ft) depth. With a continuously ponded water source (e.g., Large-Scale Infiltration Test performed near RWMC [Wood and Norell 1996]), advance of the wetting front through basalt from land surface to a depth of 55 m (180 ft) was about 5 m/day (16 ft/day).

The sometimes rapid downward movement of the wetting front through fractures and rubble zones is slowed as moisture is stored in sediment and basalt or is diverted laterally by geologic media with contrasting hydraulic conductivities (e.g., dense basalt layers or sedimentary interbeds). In the Large-Scale Infiltration Test (Dunnivant et al. 1998), water moved predominantly vertically through fractured basalt to the B-C sedimentary interbed at a depth of 55 m (180 ft), but perching and lateral movement were reported above the B-C sedimentary interbed.

Lateral underflow from the Big Lost River and spreading areas (see Figure 2-2) may provide additional sources of water to the SDA subsurface. Rightmire and Lewis (1987) and Hubbell (1990) present evidence suggesting that spreading areas are a source for perched water in basalt above the C-D interbed in Well USGS-92. Water movement from spreading areas to the SDA was documented by the arrival of a naphthalene sulfonate tracer in perched water at Well USGS-92, less than 91 days after introducing the tracer into the spreading areas (Nimmo et al. 2002). Investigators hypothesize that water from the spreading areas moves primarily downward, but a portion is diverted laterally by perching above layers having low hydraulic conductivity.

In general, infiltration inside the SDA appears to be higher than outside the SDA. McElroy (1990) found higher (i.e., comparatively wetter) water potentials in surficial sediment inside the SDA compared to surficial sediment outside the SDA. Cecil et al. (1992) used Cl-36 and tritium to estimate recharge rates outside the SDA of 0.36 to 1.1 cm/year (0.14 to 0.43 in./year) at a site near the northern boundary of the SDA. In contrast, McElroy (1993) and Bishop (1998) estimated recharge inside the SDA that ranged from 0.1 to 49.4 cm/year (0.04 to 19.5 in./year) during spring snowmelt, based on neutron probe logging. Advanced tensiometers in the B-C interbed recorded higher water potentials inside than outside the SDA (McElroy and Hubbell 2003). McElroy and Hubbell (2003) suggested that wetter conditions inside the SDA may be the result of run-off from snowmelt and high intensity rains that collect in low-lying areas inside the SDA (e.g., drainage ditches or open pits or trenches). These collection areas may have focused and intensified recharge in the SDA.

In addition to recharge rates noted above, recharge rates in the deep vadose zone at RWMC have also been estimated. Net infiltration (or recharge) rates of 3.8 and 9.2 cm/year (1.5 and 3.5 in.) in the C-D sedimentary interbed were calculated using average water contents of five interbed core samples and average hydraulic parameters developed for the C-D sedimentary interbed (Magnuson and McElroy 1993). Using in situ water potentials from advanced tensiometers and averaged hydraulic parameters developed by Magnuson and McElroy (1993), McElroy and Hubbel (2003) estimated net infiltration rates of 1 to 32 cm/year (0.4 to 12.6 in./year). Hubbell et al. (2004) also estimated flux in the deep vadose zone at RWMC using in situ water-potential measurements. However, unlike two previous investigations, the Hubbell et al. (2004) study paired each advanced tensiometer with a unique set of hydraulic parameters for each sedimentary interbed. Mean flux estimates from the C-D interbed ranged from 0.2 to 213 cm/year (0.8 to 83.8 in./year). Hubbell et al. (2004) suggested that the wide range (i.e., three orders of magnitude) in estimates were related to a high degree of uncertainty in hydraulic properties.

***2.2.9.2 Perched Water.*** Perched water at the INL Site forms when a layer of dense basalt or fine sedimentary materials occurs with a hydraulic conductivity that is sufficiently low so that downward movement of infiltrating water is restricted. Once perched water develops, lateral movement of water can occur, perhaps by up to hundreds of meters. When perched water accumulates, hydraulic pressure head increases, and water flows through the less-permeable perching layer and continues its generally vertical descent. If another restrictive zone is encountered, perching may occur again. The process can continue, forming several bodies of perched water between land surface and the water table. The volume of water contained in bodies of perched water fluctuates with the amount of recharge available from precipitation, surface water, and anthropogenic sources (e.g., evaporation ponds). Perching behavior tends to slow downward migration of percolating fluids that may be flowing rapidly under transient near-saturated conditions through the vadose zone. Historically, perched water has been found beneath RWMC, the Materials and Fuels Complex, RTC, and INTEC.

Perched water is often transitory beneath RWMC, especially at shallow depths, such as at the base of the surficial sediments. Shallow perched water is usually associated with snowmelt and localized run-off and, periodically, in response to large precipitation events. However, deep perched water has been present for extended periods in several wells. Bodies of perched water have been identified at two depth intervals at Waste Area Group 7: (1) approximately 24 to 27 m (80 to 90 ft) below land surface and (2) 61 to 67 m (200 to 220 ft) below land surface, corresponding to the sedimentary B-C and C-D interbeds, respectively. Perched water typically occurs in fractured basalt above the interbeds. Locations where perched water has been observed are shown in Figure 2-14.

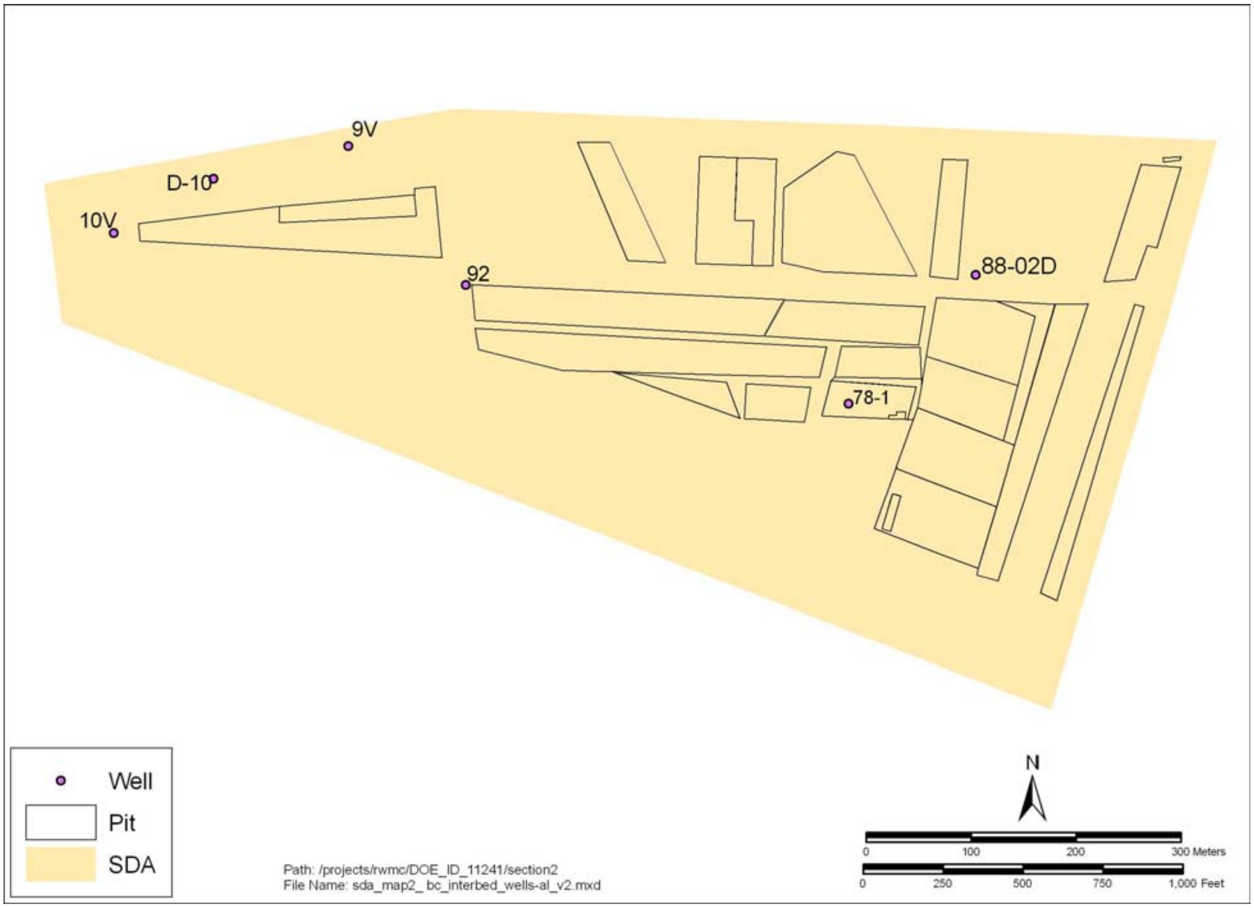



Figure 2-14. Perched water wells at the Radioactive Waste Management Complex.

Perched water has been consistently observed in two wells associated with the C-D interbed: (1) Well USGS 92, located near the center of the western half of the SDA, and (2) Well 8802D, located in the northeastern part of the SDA (Hubbell 1993, 1995; McElroy 1996). Wells USGS 92 and 8802D are the only wells that routinely yield a perched water sample. Monitoring of perched water levels from February through July 2004 show the presence of perched water at both of these wells during that period (Hubbell et al. 2005).

In 1992, perched water was detected in Well D10 (Hubbell 1992), which is completed approximately 6.1 m (20 ft) above the C-D interbed. The water level was relatively constant from March to mid-June 1992, but then showed fluctuations to the end of the monitoring period (October 1992). Perched water was last detected at Well D10 in January and February 2002. Monitoring from March 2002 through September 2004 did not detect presence of perched water (Hubbell et al. 2005).

Wells 78-1, 10V, and 9V are three locations where perched water has been observed most frequently in association with the B-C interbed. Between 1993 and May 1995, perched water was observed in Well 78-1 over three different periods: from March through May 1993, November 1993 through April 1994, and November 1994 through April 1995. These water levels were based on continuous transducer measurements and reference-level checks with steel tapes. Perched water thicknesses of up to 0.3 m (1 ft) were observed (McElroy 1996). Well 78-1 was rebuilt in November 1995 because of questions on the origin of perched water in the well. No perched water has been recorded at Well 78-1 since November 1995.

Well 10V, drilled in the western part of the SDA in 1994 as a vapor monitoring well, contained perched water at thicknesses ranging from 0.2 to 0.4 m (0.8 to 1.2 ft) when checked in December 1994; January, February, and April 1995; and July 1996 (McElroy 1996). Perched water has not been detected in Well 10V since periodic monitoring was reinitiated in January 2002. Perched water is occasionally detected at Well 9V. In April 1994, 0.6 m (2 ft) of water was detected at Well 9V. This water had drained by November 1994, and perched water was not detected during the remainder of the monitoring period (i.e., to April 1996). Hubbell et al. (2005) reported a similar occurrence in March 2004, when perched water was again detected at Well 9V and drained over the following 6 months, as recorded by the pressure transducer.

Sources of perched water at RWMC may be (1) surficial infiltration, (2) water moving laterally from spreading areas of the Big Lost River, or (3) a combination of sources. A tracer test conducted by USGS confirmed that at least some of the perched water in Well USGS 92 beneath RWMC originated from spreading areas (Nimmo et al. 2002). Four lined sewage evaporation ponds located approximately 122 m (400 ft) south of RWMC should not be a source for perched water. Two of the evaporation ponds collect sanitary wastewater from current RWMC operations and are lined with an impermeable plastic membrane. The remaining two ponds were built to support Pit 9 remediation and have compacted soil liners, but have not been used (INEEL 2001).

***2.2.9.3 Snake River Plain Aquifer.*** The Snake River Plain Aquifer, which consists of saturated basalt and sediment, is one of the largest aquifers in the United States (Irving 1993) and was classified as a sole-source aquifer by the U.S. Environmental Protection Agency in 1991 (56 FR 50634, 1991). Location of the INL Site relative to the aquifer is illustrated in Figure 2-1. Generally, groundwater flows in the aquifer from northeast to southwest. The Snake River Plain Aquifer is defined as the saturated portion of a series of basalt flows and interlayered pyroclastic and sedimentary material that underlie the eastern Snake River Plain. The aquifer extends from Bliss, Idaho, and Hagerman Valley on the west to Ashton, Idaho, and Big Bend Ridge on the northeast. Lateral boundaries formed at the points of contact of the aquifer, with less permeable rock at the margins of the plain. The aquifer arcs approximately 354 km (220 mi) through the eastern Idaho subsurface and varies in width from approximately 80 to 113 km (50 to 70 mi). Total area of the aquifer is approximately 25,000 km$^2$ (9,600 mi$^2$). General features of the aquifer beneath the INL Site and RWMC are described in the following subsections.

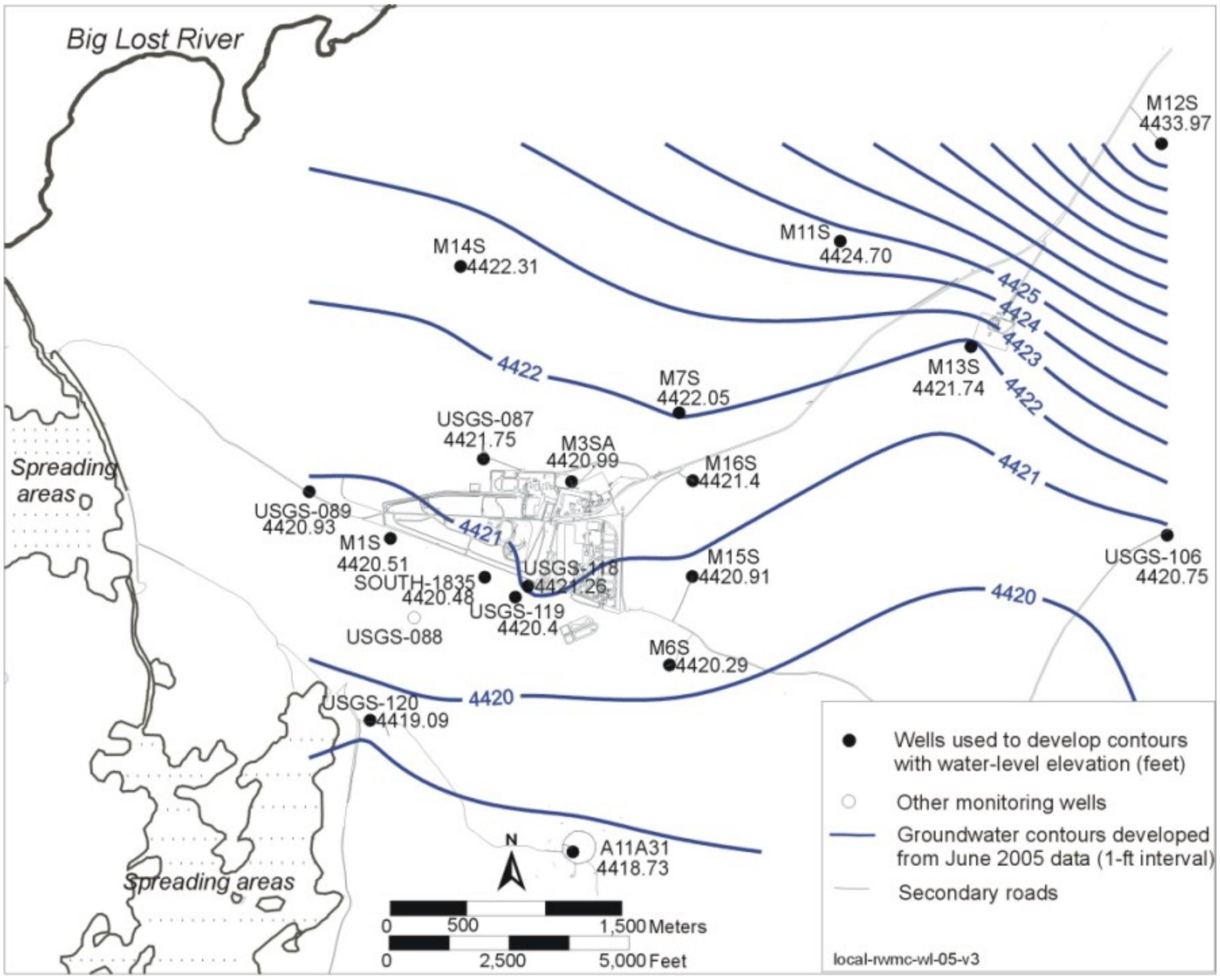
***2.2.9.3.1 Features of the Aquifer Beneath the Idaho National Laboratory Site—*** Depth to groundwater at the INL Site ranges from approximately 61 m (200 ft) below land surface in the north to more than 274 m (900 ft) in the south (Becker et al. 1996). The aquifer contains numerous, relatively thin basalt flows extending 1,067 m (3,500 ft) below land surface. In addition, the Snake River Plain Aquifer contains sedimentary interbeds that are typically discontinuous. The aquifer has been estimated to hold 2.5E+12 m$^3$ (2.02E+09 acre-ft) of water, which is approximately equivalent to the amount of water contained in Lake Erie, or enough water to cover the entire State of Idaho 1.2 m (4 ft) deep (Hackett, Pelton, and Brockway 1986). Water is pumped from the aquifer primarily for human consumption and irrigation (Irving 1993).

Aquifer permeability is controlled by distribution of highly fractured basalt flow tops, interflow zones, lava tubes, fractures, vesicles, and intergranular pore spaces. The variety and degree of interconnected water-bearing zones complicate direction of groundwater movement locally throughout the aquifer. Permeability of the aquifer varies considerably over short distances; but generally, a series of basalt flows includes several excellent water-bearing zones.

The aquifer is recharged primarily by infiltration from rain and snowfall that occurs within drainage basins surrounding the eastern Snake River Plain and from deep percolation of irrigation water. Annual recharge rates depend on precipitation, especially snowfall. Regional groundwater flows to the south–southwest, though local flow direction can be affected by recharge from rivers, surface water spreading areas, and heterogeneities in the aquifer. Estimates of flow velocities within the aquifer range from 0.1 to 6.1 m/day (0.4 to 20 ft/day) (Sorensen et al. 2000; Irving 1993). Flow in the aquifer is primarily through fractures, interflow zones in the basalt, and in highly permeable rubble zones located at flow tops. The aquifer is considered heterogeneous and anisotropic (i.e., having properties that differ depending on the direction of measurement) because of permeability variations within the aquifer that are caused by basalt irregularities, fractures, void spaces, rubble zones, and sedimentary interbeds. Heterogeneity is responsible for variability in transmissivity values (i.e., a measure of the ability of the aquifer to transmit water) through the aquifer. Transmissivity values measured in INL Site wells range from 1.0E-01 to 1.1E+06 $m^2$/day (1.1E+00 to 1.2E+07 $ft^2$/day) (Wylie et al. 1995). In general, water quality is preserved because the extensive vadose zone filters chemicals and pollutants from the irrigation and wastewater that pass through the aquifer. Concerns about groundwater contamination from INL Site operations have prompted an extensive monitoring system over the entire INL Site (Irving 1993).

***2.2.9.3.2 Features of the Aquifer Upgradient, Beneath, and Downgradient of the Radioactive Waste Management Complex—***The Snake River Plain Aquifer lies approximately 180 to 197 m (580 to 650 ft) below land surface near RWMC, according to the latest water-level measurements from June 2005. The level of the water table and flow rates fluctuate in correspondence with meteorological conditions, season, volume of discharge to spreading areas, and other factors.

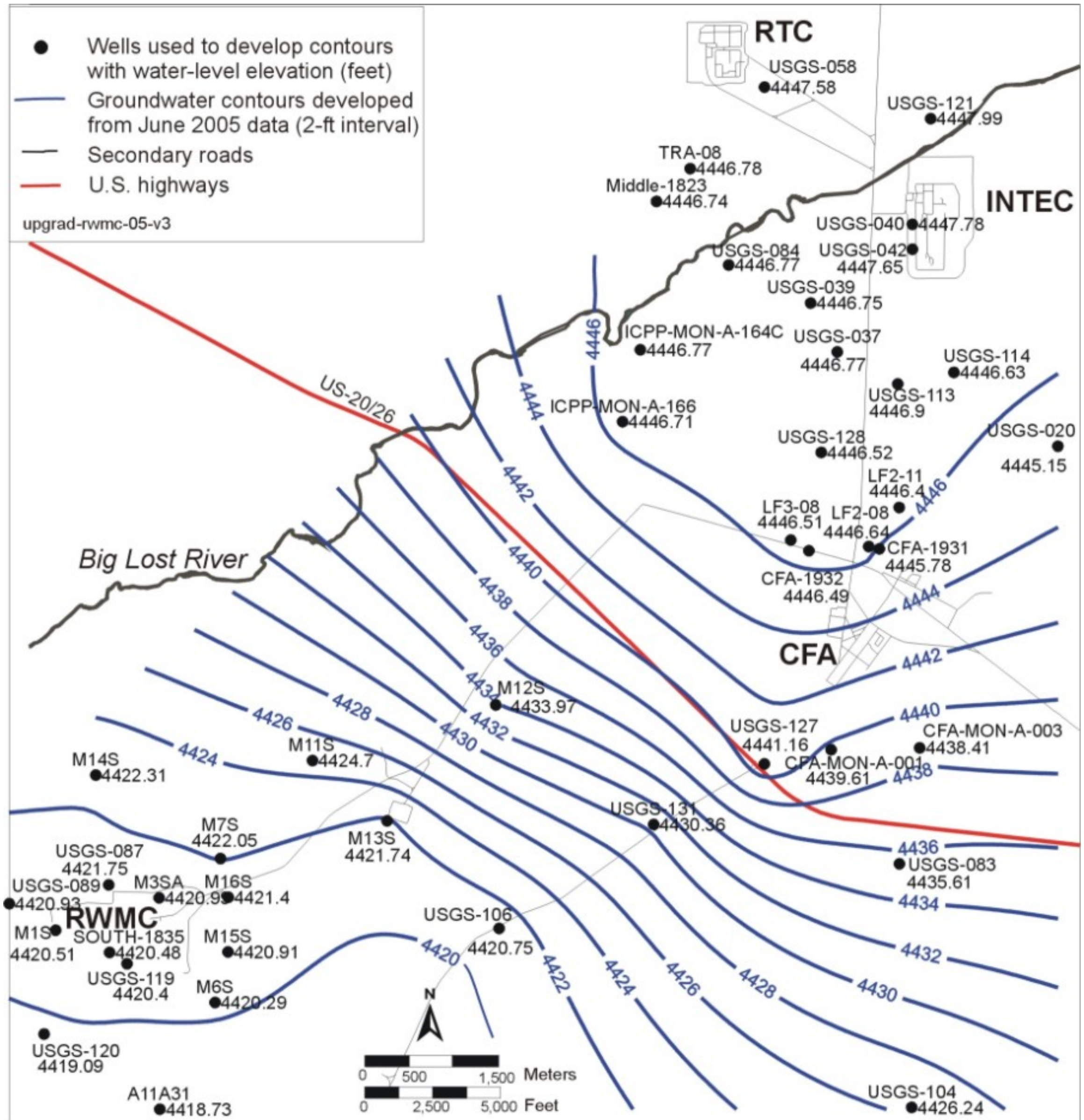
Groundwater levels from June 2005 for the RWMC area and upgradient and downgradient areas are shown in Figures 2-15, 2-16, and 2-17, respectively. Estimating direction and rate of groundwater flow near RWMC is complicated by the anisotropic and heterogeneous nature of the eastern Snake River Plain basalt. In general, direction of local groundwater flow at RWMC is from north–northeast to south–southwest (see Figure 2-16). The local water-level map for RWMC (see Figure 2-15) indicates that the groundwater gradient across the RWMC area is relatively flat (0.000337 ft/ft from Well M14S to Well USGS-120 and 0.000356 ft/ft from Well M7S to Well A11A31). The upgradient water-level map shows that INTEC and RTC are probably upgradient of RWMC (see Figure 2-16). Compared to the RWMC area, the regional gradient from Well LF3-08 to Well M13S at 0.00139 ft/ft is much higher. The downgradient map (see Figure 2-17) shows that Wells USGS-009 and USGS-109 are downgradient of wells in the immediate vicinity of RWMC. Both wells are located on or near the INL Site boundary and are currently monitored by Waste Area Group 10. Groundwater gradients south of the RWMC area are similar to gradients in the immediate vicinity of RWMC. The regional gradient south of RWMC from Well USGS-120 to Well USGS-009 is 0.000194 ft/ft and from Well USGS-120 to Well USGS-109 is 0.00018 ft/ft. Gradients calculated from 2005 data for the RWMC area and upgradient areas are similar to gradients previously calculated by Holdren et al. (2002).




Note: Water levels shown on this figure reflect reference elevations and borehole deviation corrections at the time of map creation.

G1555-10

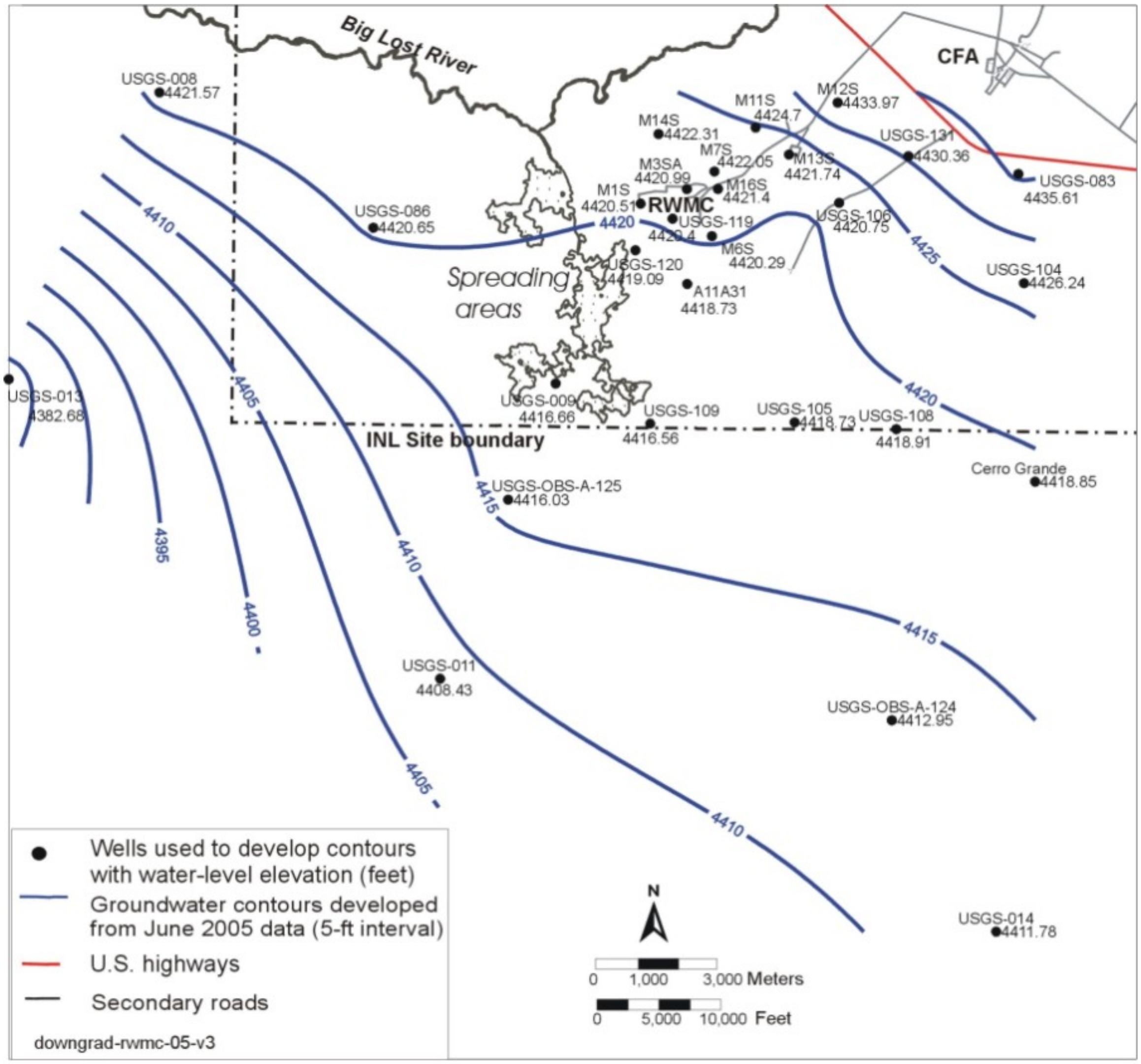
Figure 2-15. Aquifer water-level contours in the vicinity of the Radioactive Waste Management Complex, based on data collected in June 2005.




Note: Water levels shown on this figure reflect reference elevations and borehole deviation corrections at the time of map creation.

G1555-11

Figure 2-16. Aquifer water-level contours upgradient of the Radioactive Waste Management Complex, based on data collected in June 2005.




Note: Water levels shown on this figure reflect reference elevations and borehole deviation corrections at the time of map creation.

G1555-12

Figure 2-17. Aquifer water-level contours downgradient of the Radioactive Waste Management Complex, based on data collected in June 2005.

Water levels in the southern portion of RWMC area have exhibited local perturbations and seemingly anomalous behavior. For example, Well USGS-88, located directly south of RWMC, exhibits flow behavior that is not well understood (see Figure 2-15). Water-level and pump-test data from Well USGS-88 indicate that the well may penetrate a region that is hydraulically isolated from the main body of the active part of the aquifer beneath RWMC (Burgess, Higgs, and Wood 1994). Pump test results from RWMC area wells, including Well USGS-88, show that a region of low permeability is present south and southwest of RWMC (see Figure 2-18) (Wylie and Hubbell 1994; Wylie 1996). Wylie and Hubbell (1994) suggest the low transmissivity area has some form of geologic control. The geologic controls may include intersecting volcanic dikes from the Arco Volcanic Rift Zone (see Figure 2-7), lateral changes in basalt properties with distance from a volcanic vent, differential subsidence, or sediment-infilled zones within the basalt. In Fiscal Year 2003, six single well pump tests were conducted on aquifer monitoring wells that previously did not have transmissivity estimates (Jolley 2003). The additional tests were for Wells M11S, M13S, M14S, M15S, M16S, and M17S. In Figure 2-18, results of the additional tests are posted at the well locations, along with previous estimates. Only Well M17S comes close to the low-permeability region assigned, and it has an estimated transmissivity of 500 $ft^2$/day. This transmissivity is lower than that of many of the upgradient wells, but is higher than transmissivities for the low-permeability region. Jolley (2003) also concludes the hydraulic conductivity of the filter pack material does not impede water flow to these wells.

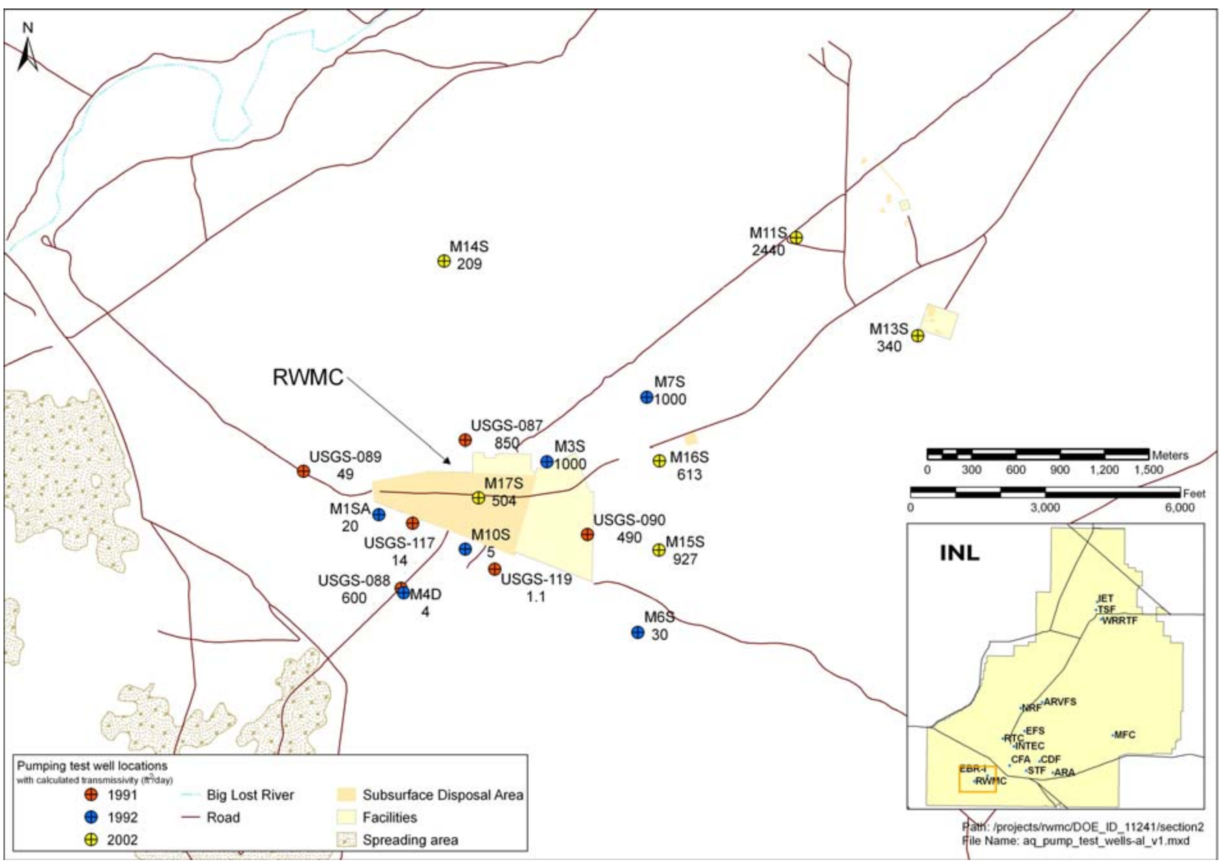



Figure 2-18. Pump test results from Radioactive Waste Management Complex area wells.

Additional information about hydrological conditions under and near RWMC was documented by Burgess, Higgs, and Wood (1994). Results from large-scale aquifer stress and infiltration tests (Wylie et al. 1995) have been used in a simulation study (Magnuson and Sondrup 1998) to develop field-scale hydraulic and transport parameters for Operable Unit 7-13/14 subsurface modeling.

## 2.3 Geologic and Hydrologic Investigations at the Radioactive Waste Management Complex

Several geologic and hydrologic investigations have been implemented over the last several years, including expanded vadose zone monitoring, tracer tests, and an assessment of the influence of upgradient contamination of the aquifer beneath RWMC. This section describes two vadose zone monitoring networks at RWMC (i.e., advanced tensiometers and lysimeters) and tracer studies to investigate the effect of spreading areas on the subsurface beneath the RWMC area and potential upgradient contamination of the aquifer beneath RWMC.

Until August 1996, a network of neutron probe access tubes also was monitored. Monitoring data for these probes intermittently span a little more than a decade, from 1986 through the summer of 1996. Some additional monitoring of NAT-17 was conducted after 1996 in support of soil-gas monitoring for tritium and C-14 near a buried beryllium block (see Section 3.9 for a summary). Holdren et al. (2002) provide detailed information about neutron probe access tubes and monitoring results.

### 2.3.1 Advanced Tensiometer Investigation

Advanced tensiometers were developed to monitor infiltration, distribution, and drainage of water under unsaturated conditions in the deep vadose zone. A network of these instruments was installed in the vadose zone beneath and adjacent to the SDA at depths ranging from 2.7 to 117 m (9 to 385 ft) below land surface. Monitoring the network supports the decision process for Operable Unit 7-13/14 (Holdren and Broomfield 2004) and the following specific objectives:

- Assess the current conceptual model of water transport in the unsaturated zone beneath RWMC
- Provide field-scale data for hydrologic model calibration and prediction
- Define soil-water conditions within sedimentary interbeds and basalt beneath RWMC environs before the system is affected by remedial action for the following purposes:
    - Develop a baseline description of water potentials in the area
    - Determine long-term status of water potentials beneath buried waste
    - Detect and monitor movement of wetting fronts to instrumented depths
    - Calculate limits for local net infiltration rates
- Detect optimal timing for lysimeter sampling by sensing presence of soil moisture
- Assess lateral movement of water from spreading areas in conjunction with planned tracer tests.

***2.3.1.1 Advanced Tensiometer Description, Well Locations, History, and Installation.*** Similar to a conventional tensiometer, the advanced tensiometer is composed of a porous cup, installed at a specified depth, with an attached pipe that extends to land surface. A volume of water is poured into the pipe to fill the cup. The advanced tensiometer has a retrievable pressure transducer that is placed inside the pipe and, in contrast to a conventional tensiometer, is seated just above the porous cup. Seating the transducer seals the water chamber in the cup from water in the pipe. Water in the cup moves into or out of the formation until the partial vacuum in the cup is equal to subatmospheric water pressure in the surrounding soil. Subatmospheric water pressure is measured by the transducer and is considered equivalent to water potentials of the surrounding medium. At RWMC, these transducers are connected to data loggers, which collect measurements every 2 to 4 hours. The data loggers are downloaded monthly.

Locations of 26 wells that comprise the advanced tensiometer network are shown in Figure 2-19. Three wells (i.e., Wells 76-5, 77-2, and 78-1) were instrumented during earlier programs. Well 76-5 was cored in 1976 (Humphrey and Tingey 1978) and monitored perched water until advanced tensiometers were installed in June 1996 (McElroy and Hubbell 2001). Similarly, Wells 77-2 and 78-1 (drilled in 1977 and 1978, respectively) monitored perched water until advanced tensiometers were installed in December 1995. Portable tensiometers were installed at the bottom of both Wells 77-2 and 78-1 in December 1999. Seventeen wells were installed and instrumented as part of the Operable Unit 7-13/14 hydrologic characterization activities in 2000. These well names begin with "O" for outside the SDA or "I" for inside the SDA. Dooley and Higgs (2003) describe drilling and well-completion information for these "I" and "O" wells.

Six new wells (i.e., RWMC-2004, -2005, -2006, -1935, -1936, and -1898) were instrumented with advanced tensiometers in 2004 (Oberhansley 2004; Oberhansley and Hubbell 2005; ICP 2004). Tensiometer depths and the lithology adjacent to each tensiometer are listed in Table 2-2. In general, tensiometers were installed in a silica-flour slurry that was placed around the porous cup to obtain a hydraulic connection between the cup and the geologic formation (Dooley and Higgs 2003). Granular bentonite was used to seal the remainder of the borehole between instrumented depths. Installation methods for Wells 76-5, 77-2, and 78-1 differed in that the porous cups of the tensiometers were placed in silt loam. In Well 76-5, granular bentonite layers were placed above and beneath loam-filled intervals with coarse sand to isolate the monitoring intervals. In Wells 77-2 and 78-1, granular bentonite was used to isolate silt-loam monitoring intervals (Hubbell et al. 2002).

***2.3.1.2 Advanced Tensiometer Monitoring Results.*** Yearly data summaries and evaluations resulting from advanced tensiometer monitoring are presented in a series of reports: McElroy and Hubbell 2001, 2003, 2004a, and 2004b. Conclusions are summarized in the following paragraphs.

After several years of near- and above-average precipitation from 1995 through 1999, an infiltration event was tracked to 17.3 m (57 ft) below land surface at a nested advanced tensiometer location (i.e., Well 76-5) in 1999 (Hubbell et al. 2002). At that time, Well 76-5 was one of only three advanced tensiometers in the SDA and the only location with nested tensiometers capable of tracking a deep recharge event. Recharge followed the spring thaw and was attributed to the local topographic low area around Well 76-5, which allowed water to drain from the surrounding area and collect at the well.

In contrast to the 1999 recharge event, advanced tensiometer measurements, from spring 2000 (when the "I" and "O" well monitoring began) through September 2003, indicate either steady-state or slowly changing, temporal water potentials at monitored basalt and sedimentary interbed locations to 73.5 m (241 ft) below land surface at RWMC. Approximately half of the monitored locations were exhibiting constant temporal water potentials consistent with steady-state conditions. However, long-term drying trends were shown by the remaining locations, except for two. These two exceptions showed increasing water potentials over the 3-1/2-year period. The most pronounced drying occurs in the shallower (i.e., less than 12 m [39 ft]) basalt and sediment (McElroy and Hubbell 2003). The long-term drying trends evidenced in the shallow and deep vadose zone are attributed to less-than-average precipitation over the 2000–2003 period (McElroy and Hubbell 2003, 2004a, 2004b).

Water potential data in the B-C sedimentary interbeds suggest wetter conditions inside the SDA than outside the SDA. McElroy and Hubbell (2003) suggest the wetter conditions inside the SDA may be the result of run-off from snowmelt and high-intensity rains that collect in low-lying areas inside the SDA (e.g., drainage ditches or open pits or trenches). These collection areas may have focused and intensified recharge in the SDA.

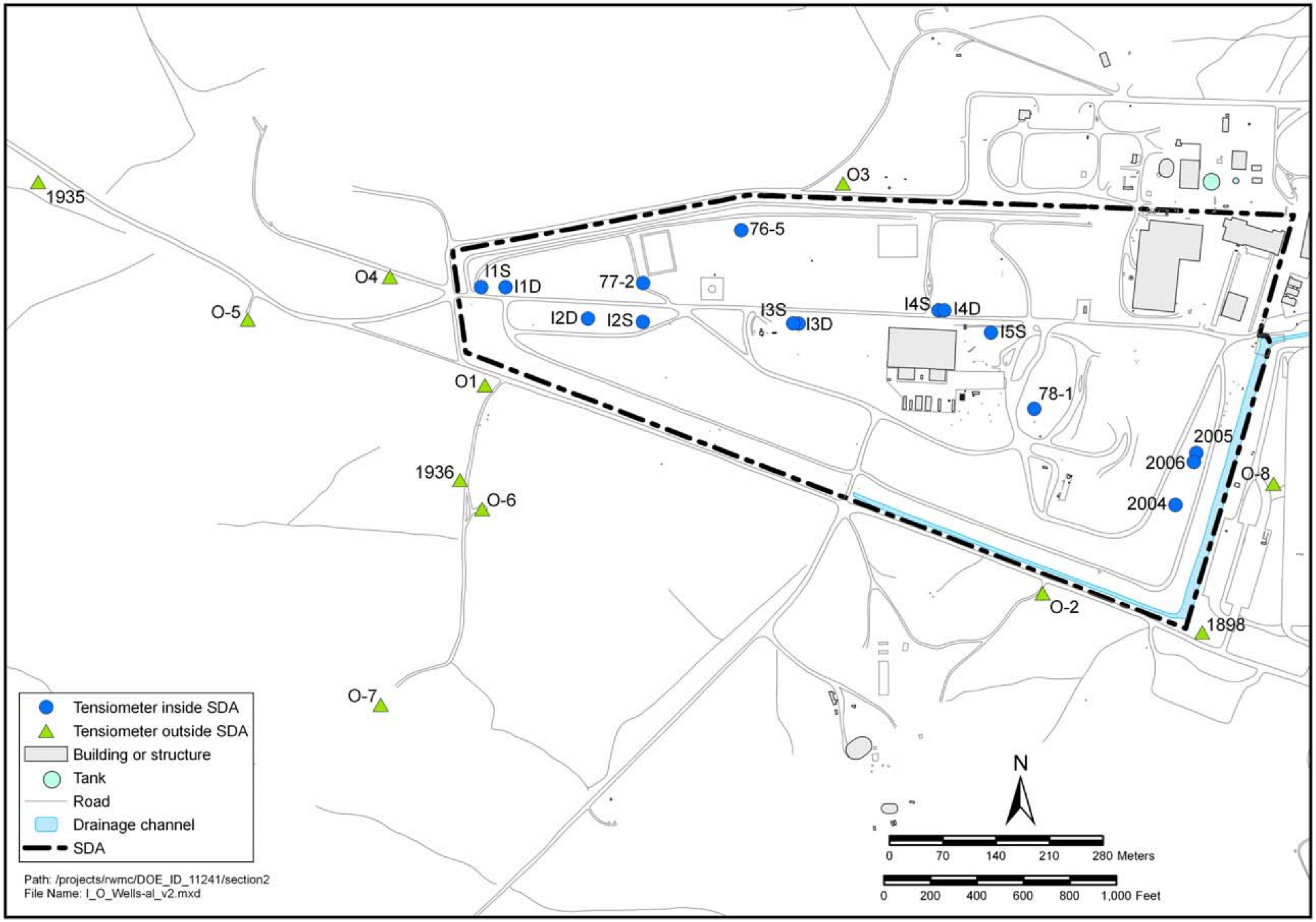



Figure 2-19. Advanced tensiometers at the Radioactive Waste Management Complex.

Table 2-2. Identifiers, depth, and lithology of advanced tensiometers at Radioactive Waste Management Complex.

| Tensiometer Identifier | Depth (m) | Depth (ft) | Lithology |
|---|---|---|---|
| I1S-31[a] | 31.4 | 103 | B-C interbed |
| I1D-69[a] | 69.2 | 227 | C-D interbed |
| I2S-29[a] | 28.7 | 94 | Unknown, no core recovered and no gamma log |
| I2D-54[a] | 53.6 | 176 | Massive basalt |
| I2D-68[a] | 68.0 | 223 | C-D interbed |
| I3S-28[a] | 28.3 | 93 | B-C interbed |
| I3D-70[a] | 69.8 | 229 | C-D interbed |
| I4S-30[a] | 29.72 | 97.5 | Near contact of basalt and B-C interbed |
| I4D-69[a] | 69.2 | 227 | C-D interbed |
| I5S-30[a] | 30.39 | 99.7 | Near contact of basalt and B-C interbed |
| O1-30[a] | 29.6 | 97 | B-C interbed, no core recovered |
| O1-70[a] | 69.8 | 229 | C-D interbed, no core recovered |
| O2-33[a] | 32.6 | 107 | Near contact of basalt and B-C interbed |
| O2-74[a] | 73.55 | 241.3 | Basalt, no core recovered |
| O3-27[a] | 26.8 | 88 | Basalt |
| O3-67[a] | 67.4 | 221 | Near contact of basalt and C-D interbed |
| O4-34[a] | 33.5 | 110 | B-C interbed |
| O4-69[a] | 69.04 | 226.5 | C-D interbed |
| O5-32[a] | 32.0[b] | 105[b] | Near contact of basalt and B-C interbed |
| O6-69[a] | 69.2 | 227 | Dense vesicular basalt |
| O7-37[a] | 36.9 | 121 | B-C interbed, no core recovered |
| O7-74[a] | 73.55 | 241.3 | Rubbly basalt |
| O8-70[a] | 69.95 | 229.5 | Dense basalt |
| 76-5-7 | 6.7 | 22 | Sediment-filled fractures |
| 76-5-9 | 9.4 | 31 | A-B interbed |
| 76-5-12 | 11.6 | 38 | Rubble zone |
| 76-5-17 | 17.3 | 57 | Sediment-filled horizontal fracture |
| 76-5-24 | 24.4 | 80 | Sediment-filled fractures |
| 76-5-30 | 29.6 | 97 | Moist basalt |
| 76-5-31 | 31.4 | 103 | B-C interbed |
| 77-2-10 | 10.0 | 32.8 | A-B interbed, reddish baked silt |
| 77-2-17 | 17.1 | 56 | Basalt |
| 77-2-27 | 27.4[c] | 90[c] | Basalt |
| 78-1-11 | 10.7 | 35 | Fractured basalt with sediment infilling |
| 78-1-26 | 25.6[c] | 84[c] | Fractured basalt with sediment infilling |

Table 2-2. (continued).

| Tensiometer Identifier | Depth (m) | Depth (ft) | Lithology |
|---|---|---|---|
| 1935-13 | 12.5 | 41 | A-B interbed |
| 1935-30 | 29.9 | 98 | Fractured basalt |
| 1935-42 | 41.5 | 136 | Dense basalt |
| 1935-67 | 66.90 | 219.5 | Fractured basalt |
| 1935-72 | 72.2 | 237 | C-D interbed |
| 1935-76 | 76.2 | 250 | Basalt |
| 1935-86 | 85.6 | 281 | Basalt |
| 1935-98 | 97.78 | 320.8 | Fractured basalt |
| 1935-103 | 102.57 | 336.5 | Fractured basalt |
| 1935-109 | 108.5 | 356 | Fractured basalt |
| 1935-117 | 117.3 | 385 | Basalt |
| 1936-10 | 9.8 | 32 | A-B interbed |
| 1936-32 | 31.7 | 104 | B-C interbed |
| 1936-35 | 35.1 | 115 | B-C interbed |
| 1936-44 | 44.2 | 145 | Fractured basalt |
| 1936-56 | 56.1 | 184 | Interbed |
| 1936-64 | 64.3 | 211 | Slightly vesicular basalt |
| 1936-72 | 71.6 | 235 | C-D interbed |
| 1936-83 | 82.9 | 272 | Vesicular basalt |
| 1936-93 | 92.7 | 304 | Vesicular and fractured basalt |
| 1936-105 | 104.9 | 344 | Fractured basalt |
| 1936-114 | 113.7 | 373 | Fractured basalt |
| 2004-5 | 5.03 | 16.5 | Surficial sediment |
| 2004-31 | 31.1 | 102 | B-C interbed |
| 2004-32 | 32.3 | 106 | B-C interbed |
| 2004-74 | 73.8 | 242 | C-D interbed |
| 2004-76 | 75.9 | 249 | C-D interbed |
| 2005-3 | 2.71 | 8.9 | Surficial sediment |
| 2006-3 | 3.4 | 11 | Surficial sediment |
| 2006-33 | 32.6 | 107 | B-C interbed |
| 2006-72 | 72.2 | 237 | C-D interbed |
| 1898-69 | 68.9 | 226 | C-D interbed |

a. Actual well names contain a dash between the first letter and number (e.g., I-1S and O-4), which was removed for this nomenclature when the depth was added at the end of the tensiometer identifier.
b. Because of a discrepancy between the geologist log and the gamma log for Well O-5, the natural gamma log was used to identify interbed depth at 32.3 m (106 ft).
c. A portable tensiometer was installed at this depth.

McElroy and Hubbell (2003) estimate flux in the B-C and C-D sedimentary interbeds using a unit gradient approach and based on average in situ water potentials from advanced tensiometers and averaged hydraulic parameters for the B-C and C-D interbed sediment (Magnuson and McElroy 1993). Hydraulic parameters are estimated from laboratory-derived hydraulic properties of sedimentary interbed cores collected in an earlier study (McElroy and Hubbell 1990). Flux estimates for the C-D interbed sediment range from 1 to 32 cm/year (0.4 to 12.6 in./year), whereas flux estimates for the B-C interbed sediment range from 1 to 21,539 cm/year (0.4 to 8,480 in./year). Flux estimates for the B-C interbed sediment inside the SDA are the most variable, ranging from 5 to 21,539 cm/year (2.0 to 8,480 in./year). Flux estimates most representative of steady-state flow conditions are from 1 to 32 cm/year (0.4 to 12.6 in./year); these include all flux estimates in the C-D sedimentary interbed, but only flux estimates in B-C sedimentary interbed locations outside the SDA.

Hubbell et al. (2004) also estimate flux in the deep vadose zone at RWMC using the unit gradient method and in situ water-potential measurements from this advanced tensiometer network. However, hydraulic parameters used in this study are developed from measured hydraulic properties of core samples collected from “I” and “O” wells at RWMC. In addition, each monitored advanced tensiometer location is paired with a unique set of hydraulic parameters; assignment of hydraulic parameters is based on individual cores collected near the advanced tensiometer location rather than an averaged set of parameters for each sedimentary interbed (McElroy and Hubbell 2003). Flux estimates range from 0.2 to 10,000 cm/year (0.079 to 3,937 in./year). Estimates for the B-C sedimentary interbed range across four orders of magnitude, while flux estimates for the C-D sedimentary interbed range across three orders of magnitude. The study concludes that while tensiometer data appear to reflect in situ conditions, the laboratory-developed hydraulic properties introduce a high degree of uncertainty in flux estimates.

### 2.3.2 Lysimeter Investigations

Suction lysimeters create a vacuum inside the lysimeter and draw moisture through a porous material into the lysimeter where it can be collected for analysis. The porous material, typically ceramic or stainless steel, has tiny pores that are permeable to water but impermeable to air when wetted. The majority of lysimeters at RWMC have either ceramic or stainless steel cups. Four lysimeters with Teflon cups also were installed because of the possibility that radionuclides may sorb on ceramic cups (Hubbell et al. 1985), which could cause biased, low-detection results. Lysimeters with Teflon cups were not successful in collecting soil-water samples because low air-entry pressure prevented using a vacuum that was high enough to extract water from SDA soil.

Installation of lysimeters at RWMC began in 1985 to determine solution chemistry and to define radionuclide migration in the vadose zone (Hubbell et al. 1985). From 1985 to 1987, 32 suction lysimeters were installed in surficial sediment in and around RWMC, and seven deep lysimeters were installed in sedimentary interbeds (Hubbell et al. 1985, 1987; Laney et al. 1988). Figure 2-20 shows boreholes containing the lysimeters, and Table 2-3 lists monitored lysimeters. Because multiple lysimeters were installed in boreholes, naming protocol for the lysimeters relies on individual lysimeter numbers. Shallow lysimeters were installed in auger holes with a silica-flour slurry surrounding the lysimeter cup. A 5 to 7-cm (2 to 3-in.) layer of bentonite was placed on top of the silica flour as a moisture seal, and native sediment was used to backfill the borehole. Deep lysimeters in the B-C and C-D interbeds were installed in silica-flour slurry, and bentonite was used to seal between instrument installations in the same borehole. A silica-flour slurry with a 10-mg/L potassium-bromide tracer was used for lysimeters installed in 1986 and 1987 to determine when valid samples were collected. Presence of potassium bromide tracer in sample analysis would indicate that water applied during instrument installation is still affecting sample results; whereas, absence of the tracer would indicate that the sample is representative of local soil moisture.

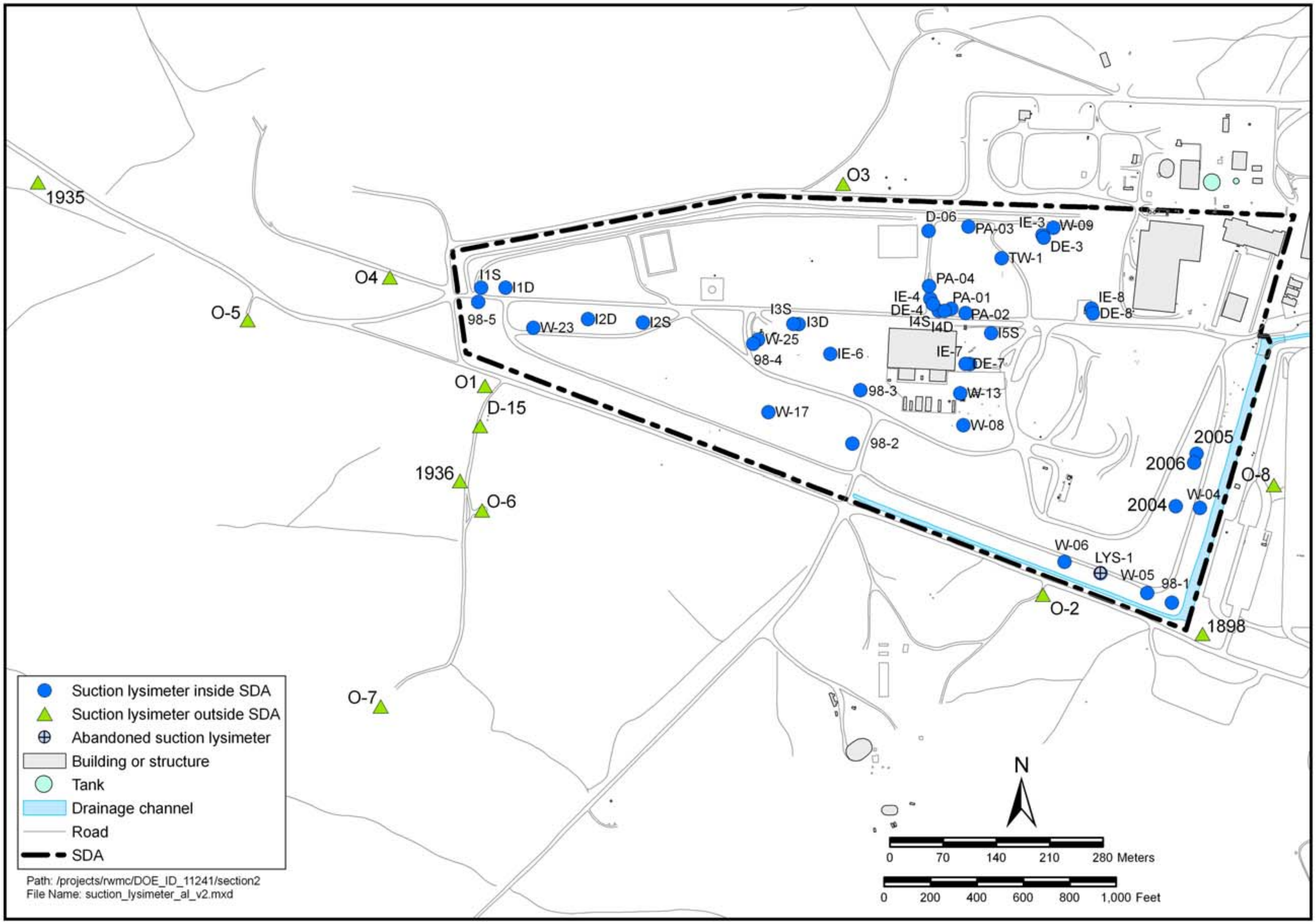



Figure 2-20. Suction lysimeters at the Radioactive Waste Management Complex.

Table 2-3. Suction lysimeters monitored at the Radioactive Waste Management Complex.

| Lysimeter | Well (Alias)[a] | Date Installed | Lysimeter Depth (m) | Lysimeter Depth (ft) | Cup Type | Status |
|---|---|---|---|---|---|---|
| L04 | W-04 | June 19, 1985 | 4.69 | 15.4 | Ceramic | Active |
| L05 | W-04 | June 19, 1985 | 1.89 | 6.2 | Ceramic | Active |
| L07 | W-23 | June 28, 1985 | 5.73 | 18.8 | Teflon | Active |
| L08 | W-23 | June 28, 1985 | 3.60 | 11.8 | Ceramic | Active |
| L09 | W-23 | June 28, 1985 | 2.35 | 7.7 | Ceramic | Active |
| L12 | W-08 | July 9, 1985 | 6.74 | 22.1 | Ceramic | Active |
| L13 | W-08 | July 9, 1985 | 3.44 | 11.3 | Ceramic | Active |
| L14 | W-08 | July 9, 1985 | 1.89 | 6.2 | Ceramic | Active |
| L15 | PA-01[b] | July 11, 1985 | 4.36 | 14.3 | Ceramic | Active |
| L16 | PA-02[b] | July 11, 1985 | 2.65 | 8.7 | Ceramic | Active |
| L23 | W-09 | September 17, 1986 | 4.51 | 14.8 | Ceramic | Active |
| L24 | W-05 | September 22, 1986 | 4.85 | 15.9 | Ceramic | Active |
| L25 | W-05 | September 22, 1986 | 3.1 | 10 | Ceramic | Active |
| L26 | W-05 | September 22, 1986 | 2.04 | 6.7 | Ceramic | Active |
| L27 | W-06 | September 23, 1986 | 3.60 | 11.8 | Ceramic | Active |
| L28 | W-25 | September 24, 1986 | 4.72 | 15.5 | Ceramic | Active |
| L29 | W-13 | September 20, 1986 | 4.3 | 14 | Ceramic | Active |
| L30 | W-13 | September 28, 1986 | 2.04 | 6.7 | Ceramic | Active |
| L31 | W-17 | September 29, 1986 | 5.97 | 19.6 | Ceramic | Active |
| L32 | W-17 | September 29, 1986 | 3.32 | 10.9 | Ceramic | Active |
| L33 | PA-03[b] | December 1994 | 3.1 | 10 | Ceramic | Active |
| L34 | PA-04[b] | December 1994 | ~8.2 | ~27 | Ceramic | Active |
| L35 | 98-1 | February 2, 1998 | 5.03 | 16.5 | Ceramic | Active |
| L36 | 98-2 | January 29, 1998 | 2.7 | 9 | Ceramic | Active |
| L37 | 98-3 | February 4, 1998 | 6.86 | 22.5 | Ceramic | Active |
| L38 | 98-4 | February 3, 1998 | 5.2 | 17 | Ceramic | Active |
| L39 | 98-5 | February 2, 1998 | 3.20 | 10.5 | Ceramic | Active |
| L40[c] | LYS-1 | 1994 | 2.01 | 6.6 | Ceramic | Abandoned |
| L41[c] | LYS-1 | 1994 | 6.00 | 19.7 | Ceramic | Abandoned |
| DL01 | D-06 | September 12, 1986 | 26.8 | 88 | Ceramic | Active |
| DL02 | D-06 | September 12, 1986 | 13.4 | 44 | Ceramic | Active |
| DL03 | TW-1 | June 25, 1987 | 69.16 | 226.9 | Ceramic | Active |
| DL04 | TW-1 | June 25, 1987 | 31.00 | 101.7 | Ceramic | Active |
| DL05 | D-15 | September 15, 1987 | 67.94 | 222.9 | Ceramic | Active |
| DL06 | D-15 | September 15, 1987 | 29.84 | 97.9 | Ceramic | Active |
| DL07 | D-15 | November 4, 1987 | 9.81 | 32.2 | Ceramic | Active |
| DL08 | I1D | ~ November 1999 | 68.3 | 224 | Stainless steel | Active |
| DL09 | I1S | ~ November 1999 | 30.8 | 101 | Stainless steel | Active |
| DL10 | I2D | ~ November 1999 | 59.7 | 196 | Stainless steel | Active |
| DL11 | I2S | ~ November 1999 | 28.0 | 92 | Stainless steel | Active |
| DL12 | I3D | ~ November 1999 | 69.5 | 228 | Stainless steel | Active |

Table 2-3. (continued).

| Lysimeter | Well (Alias)[a] | Date Installed | Lysimeter Depth (m) | Lysimeter Depth (ft) | Cup Type | Status |
|---|---|---|---|---|---|---|
| DL13 | I3S | ~ November 1999 | 28.3 | 93 | Stainless steel | Active |
| DL14 | I4D | ~ January 2000 | 69.04 | 226.5 | Stainless steel | Active |
| DL15 | I4S | ~ January 2000 | 29.6 | 97 | Stainless steel | Active |
| DL16 | I5S | ~ March 2000 | 30.08 | 98.7 | Stainless steel | Active |
| DL17 | O-1 (O1) | December 16, 1999 | 69.5 | 228 | Stainless steel | Active |
| DL18 | O-1 (O1) | December 16, 1999 | 29.3 | 96 | Stainless steel | Active |
| DL19 | O-2 | January 12, 2000 | 73.2 | 240 | Stainless steel | Active |
| DL20 | O-2 | January 12, 2000 | 32.3 | 106 | Stainless steel | Active |
| DL21 | O-3 (O3) | November 1999 | 66.8 | 219 | Stainless steel | Active |
| DL22 | O-3 (O3) | November 1999 | 26.5 | 87 | Stainless steel | Active |
| DL23 | O-4 (O4) | January 4, 2000 | 68.6 | 225 | Stainless steel | Active |
| DL24 | O-4 (O4) | January 4, 2000 | 33.07 | 108.5 | Stainless steel | Active |
| DL25 | O-5 | January 12, 2000 | 31.7 | 104 | Stainless steel | Active |
| DL26 | O-6 | November 1999 | 68.6 | 225 | Stainless steel | Active |
| DL27 | O-7 | November 1999 | 73.2 | 240 | Stainless steel | Active |
| DL28 | O-7 | November 1999 | 36.3 | 119 | Stainless steel | Active |
| DL29 | O-8 | ~ November 1999 | 69.5 | 228 | Stainless steel | Active |
| DL30 | IE-3 | Spring 2003 | 68.6 | 225 | Stainless steel | Active |
| DL31 | DE-3 | Spring 2003 | 105.2 | 345 | Stainless steel | Active |
| DL32 | IE-4 | Spring 2003 | 68.0 | 223 | Stainless steel | Active |
| DL33 | DE-4 | Spring 2003 | 141.1 | 463 | Stainless steel | Active |
| DL34 | IE-6 | Spring 2003 | 65.5 | 215 | Stainless steel | Active |
| DL35 | IE-7 | Spring 2003 | 70.4 | 231 | Stainless steel | Active |
| DL36 | DE-7 | Spring 2003 | 115.0 | 377 | Stainless steel | Active |
| DL37 | DE-7 | Spring 2003 | 125.9 | 413 | Stainless steel | Active |
| DL38 | IE-8 | Spring 2003 | 68.3 | 224 | Stainless steel | Active |
| DL39 | DE-8 | Spring 2003 | 119.8 | 393 | Stainless steel | Active |
| DL40 | S1898 (1898) | Spring 2004 | 68.6 | 225 | Stainless steel | Active |
| DL42 | RWMC-2005 (2005) | Spring 2004 | 2.71 | 8.9 | Stainless steel | Active |
| DL43 | RWMC-2006 (2006) | Spring 2004 | 71.6 | 235 | Stainless steel | Active |
| DL44 | RWMC-2006 (2006) | Spring 2004 | 55.5 | 182 | Stainless steel | Active |
| DL45 | RWMC-2006 (2006) | Spring 2004 | 32.0 | 105 | Stainless steel | Active |
| DL46 | RWMC-2006 (2006) | Spring 2004 | 22.9 | 75 | Stainless steel | Active |
| DL47 | RWMC-2006 (2006) | Spring 2004 | 3.4 | 11 | Stainless steel | Active |
| DL48 | RWMC-2004 (2004) | Spring 2004 | 73.2 | 240 | Stainless steel | Active |
| DL49 | RWMC-2004 (2004) | Spring 2004 | 30.8 | 101 | Stainless steel | Active |

Table 2-3. (continued).

| Lysimeter | Well (Alias)[a] | Date Installed | Lysimeter Depth (m) | Lysimeter Depth (ft) | Cup Type | Status |
|---|---|---|---|---|---|---|
| DL50 | RWMC-2004 (2004) | Spring 2004 | 22.6 | 74 | Stainless steel | Active |
| DL52 | RWMC-1935 (1935) | Summer 2004 | 116.8 | 383 | Stainless steel | Active |
| DL53 | RWMC-1935 (1935) | Summer 2004 | 108.2 | 355 | Stainless steel | Active |
| DL54 | RWMC-1935 (1935) | Summer 2004 | 102.26 | 335.5 | Stainless steel | Active |
| DL55 | RWMC-1935 (1935) | Summer 2004 | 85.3 | 280 | Stainless steel | Active |
| DL56 | RWMC-1935 (1935) | Summer 2004 | 75.6 | 248 | Stainless steel | Active |
| DL57 | RWMC-1935 (1935) | Summer 2004 | 71.9 | 236 | Stainless steel | Active |
| DL58 | RWMC-1935 (1935) | Summer 2004 | 66.29 | 217.5 | Stainless steel | Active |
| DL59 | RWMC-1935 (1935) | Summer 2004 | 40.8 | 134 | Stainless steel | Active |
| DL60 | RWMC-1935 (1935) | Summer 2004 | 29.3 | 96 | Stainless steel | Active |
| DL61 | RWMC-1936 (1936) | Summer 2004 | 113.1 | 371 | Stainless steel | Active |
| DL62 | RWMC-1936 (1936) | Summer 2004 | 104.2 | 342 | Stainless steel | Active |
| DL63 | RWMC-1936 (1936) | Summer 2004 | 92.0 | 302 | Stainless steel | Active |
| DL64 | RWMC-1936 (1936) | Summer 2004 | 82.3 | 270 | Stainless steel | Active |
| DL65 | RWMC-1936 (1936) | Summer 2004 | 71.0 | 233 | Stainless steel | Active |
| DL66 | RWMC-1936 (1936) | Summer 2004 | 55.5 | 182 | Stainless steel | Active |
| DL67 | RWMC-1936 (1936) | Summer 2004 | 43.6 | 143 | Stainless steel | Active |
| DL68 | RWMC-1936 (1936) | Summer 2004 | 34.4 | 113 | Stainless steel | Active |
| DL69 | RWMC-1936 (1936) | Summer 2004 | 31.4 | 103 | Stainless steel | Active |
| DL70 | RWMC-1936 (1936) | Summer 2004 | 9.1 | 30 | Stainless steel | Active |

Note: For more information on abandoned or inactive wells not listed in this table, refer to Casper, Salomon, and Olson (2006) and Meyer et al. (2005).

a. Alias is well name in Figure 2-20.
b. Boreholes PA-01 and PA-02 were located in surficial sediment a couple of feet from the edge of the Pad A asphalt pad. The lithologic log for Borehole PA-03 does not indicate augering through the asphalt pad. The lysimeter in Borehole PA-04 was installed under the asphalt pad.
c. Lysimeters L40 and L41 were abandoned in 2004 to accommodate the Beryllium Block Grouting Project.

From November 1999 through March 2000, 22 deep lysimeters (i.e., Lysimeters DL08 through DL29) were installed inside and outside SDA boundaries (Dooley and Higgs 2003) (see Figure 2-20 and Table 2-3). Porous cups on these lysimeters are stainless steel with 600 cm of water air entry pressure. Installation was similar to the procedure described previously with silica-flour slurry between layers of bentonite.

As part of remediation and monitoring activities for Pad A—an aboveground disposal area located on an asphalt pad—two lysimeters were installed in December 1994 (Parsons 1995a, 1995b). Lysimeter L33 was installed at a depth of 3 m (10 ft) below the surface of Pad A on the north side in Borehole PA-03 (see Figure 2-20). However, well logs indicate that drillers did not encounter the asphalt pad when augering Borehole PA-03; therefore, either the asphalt pad does not extend as far as Borehole PA-03 or the lysimeter is located in cover material above the asphalt pad. Lysimeter L34 was installed in a horizontal borehole under the asphalt at Pad A in Borehole PA-04. Lysimeter L34 is near the center of Pad A, approximately 50 m (165 ft) northeast of the Borehole PA-04 wellhead. Both lysimeters were installed in silica flour, and bentonite was used to seal the silica-flour layer.

Five lysimeters (i.e., L35 through L39) were installed in surficial sediment in the SDA in 1998 to assess migration of magnesium chloride in the soil (see Figure 2-20 and Table 2-3). Magnesium chloride was applied to SDA roads to suppress dust in 1984, 1985, and in the early 1990s; the chloride might contribute to corrosion of buried waste containers. Each of the lysimeters was installed as close as possible to the sediment-basalt interface. A soil slurry was placed around the porous ceramic cup, native soil was used to backfill the borehole, and a 30-cm (12-in.) layer of bentonite was placed 51 cm (20 in.) above the instrument to serve as a barrier to downhole water movement.

Suction Lysimeters L40 and L41 were installed in 1994 to collect water samples near buried beryllium blocks near the western end of Soil Vault Row 20 to validate calculated beryllium corrosion and radionuclide release rates used in low-level waste (LLW) operations performance assessments (Case et al. 2000). Lysimeter cups were placed in native fill material with a layer of sand above and below the lysimeter, and the borehole was backfilled with bentonite. Several attempts were made to collect a sample from Lysimeter L40, but sufficient vacuum to collect a sample could not be maintained. However, the deeper lysimeter, L41, yielded sufficient sample volume to analyze for chloride, C-14, and tritium (Ritter and McElroy 1999). Both Lysimeters L40 and L41 were abandoned in 2004 to accommodate the Beryllium Block Grouting Project at Soil Vault Row 20 in the SDA.

Lysimeter DL40 was installed outside the SDA in Well South-1898 in October 2003, replacing two previous wells: M10S (abandoned in 2002) and South-1835 (abandoned in April 2003). Although Wells M10S and South-1835 were abandoned, the location remained critical in monitoring possible migration of contaminants to the Snake River Plain Aquifer; therefore, Well South-1898 was planned as a replacement aquifer monitoring well (ICP 2004). However, drilling problems resulted in completing Well South-1898 as an instrumented borehole rather than an aquifer monitoring well.

In 2004, additional lysimeter installations carried the prefix “DL” to maintain consistent nomenclature.

Lysimeters DL42 through DL50 were installed at various depths in the SDA in April 2004. These lysimeters are in areas of recognized moist, fractured basalt, and permeable interbeds. Placement of these lysimeters focused on monitoring water movement around and through the B-C and C-D interbeds to understand formation of perched water in the subsurface. These lysimeters supply geologic and hydraulic data useful to predict the rate and direction of water movement in the vadose zone. The DL51 location would not accept a lysimeter and is not operable.

Lysimeters DL52 through DL70 were installed outside the SDA at varying depths in August 2004. These discrete depths were chosen for their association with moisture in the vadose zone, to help characterize the nature and extent of subsurface basalt and interbeds in that particular area, and to provide data on groundwater movement within the vadose zone.

Four perched wells within the SDA do not have permanent lysimeters installed: Wells 10V, USGS-92, 8802-D, and D-10. A portable suction lysimeter is installed in these wells during quarterly sampling and removed after sampling is complete. Well DE6 had an empty 3.2-cm (1.25-in.) stainless steel pipe that accommodated a portable suction lysimeter. This well also is sampled quarterly.

Lysimeters DL30 through DL39 were installed in monitoring and extraction wells for Operable Unit 7-08 in late 2002 and early 2003. These lysimeters were placed at various depths to characterize hydraulic and geologic data for predicting the rate at which water and contaminants move through the vadose zone.

Sixty-five wells within and outside the SDA (excluding the waste zone) contain approximately 100 lysimeters placed at various depths in the vadose zone. These lysimeters are sampled quarterly, and sample water is shipped to an off-INL Site laboratory for analysis. An analyte priority list is established quarterly to define use of limited sample volumes. Vacuums are applied to selected lysimeters before sampling to help draw soil water into the lysimeters and increase volume. Those lysimeters are monitored with pressure loggers to maintain vacuum in the lysimeter.

### 2.3.3 U.S. Geological Survey 1999 Spreading Area Tracer Test

A tracer test was conducted at two of four spreading areas near the SDA to investigate long-range flow paths through the vadose zone (Nimmo et al. 2002). The four spreading areas receive water as a diversion from the Big Lost River during periods of high surface water flow. Rarely are all four spreading areas used in a given season. In some years, no diversions are necessary, and all spreading areas remain dry.

In June 1999, USGS applied a 1,5-naphthalene disulfonic acid tracer to Spreading Areas A and B (Nimmo et al. 2002). The tracer was a dry powder that was placed in a sack and introduced into spreading area water by a boat, which traversed accessible wet areas of Spreading Areas A and B on the first day, towing the sack of tracer through the water. Using the same method on the second day, the tracer was again introduced into Spreading Area B in the lobe that extends north toward the SDA (see Figure 2-21). Key findings of the tracer test are as follows:

- Low-permeability layers of the unsaturated zone (i.e., interbeds) divert some flow horizontally

- Horizontal movement does not prevent rapid transport to the aquifer under ponded conditions at the surface, as indicated by detection of tracer in aquifer Well USGS-120 within 9 days

- Because tracer was detected in perched water at Well USGS-92, spreading area water from more than 1 km (3,281 ft) away contributes some perched water beneath the SDA

- Tracer in USGS-92 was detected within 90 days and may have arrived sooner, indicating that horizontal convective transport rates within the unsaturated zone exceed 14 m/day (46 ft/day)

- The 1,5-naphthalene disulfonic acid proved to be a stable and conservative tracer in this application and can be used to investigate flow paths over distances of at least 1.3 km (4,264 ft) and over a period of several months.

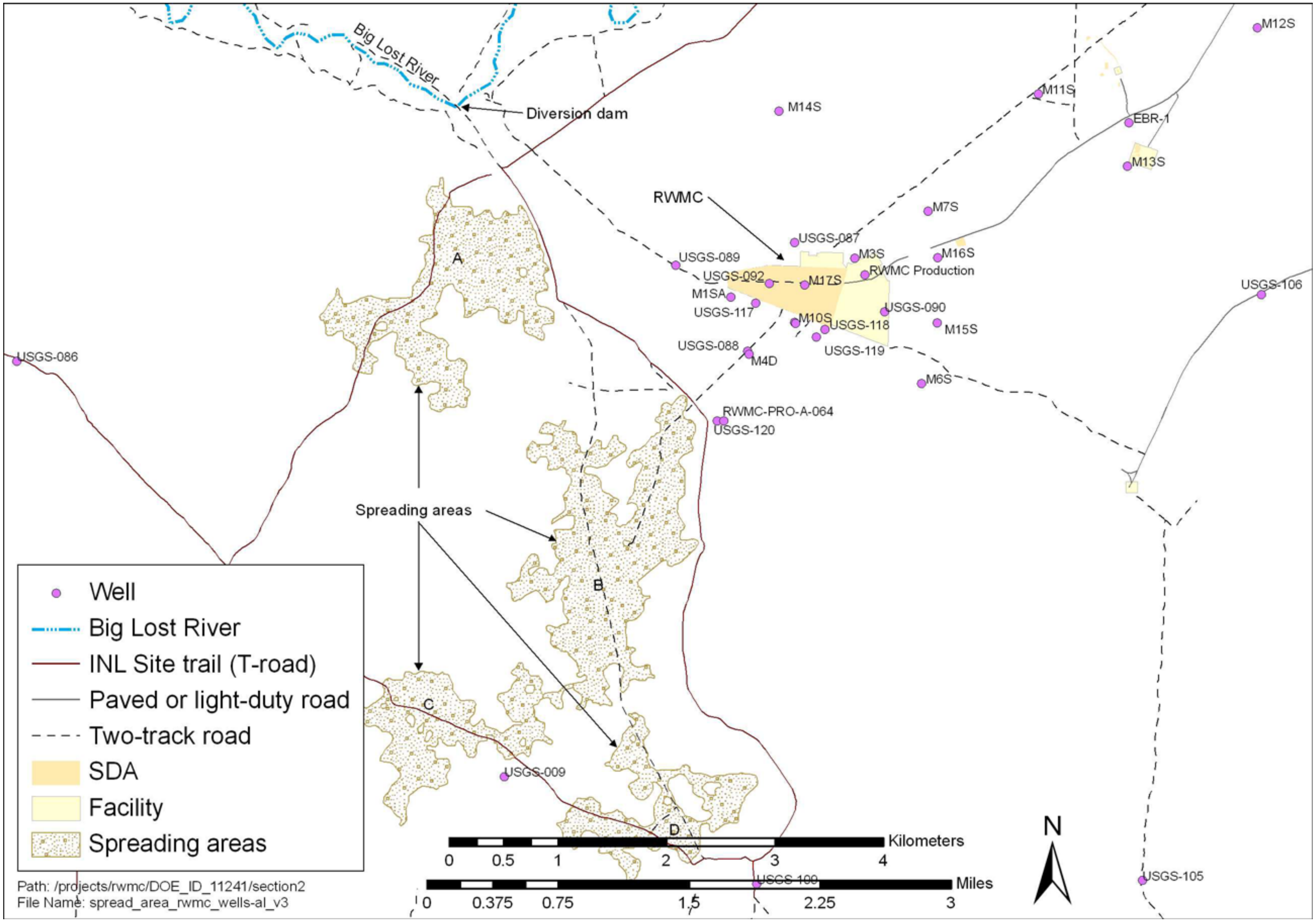



Figure 2-21. Surface water features and select monitoring wells near the Radioactive Waste Management Complex.

### 2.3.4 Effects of Upgradient Aquifer Plumes

This section summarizes data and conclusions from two geochemical studies: Waste Area Group 10 Annual Remedial Investigation and Feasibility Study (DOE-ID 2006) and Evaluation of Aquifer Contaminants Upgradient from RWMC (Roddy and Koeppen 2004)[a]. These geochemical studies used anthropogenic compounds to determine sources of contaminants in the aquifer beneath RWMC, identify groundwater flow paths from INTEC and RTC, and determine the source of an anion anomaly south of RWMC. Groundwater flow paths were identified to develop and calibrate the Operable Unit 10-08 Sitewide Groundwater Model (DOE-ID 2004).

***2.3.4.1 Description of Waste Area Group 10 Geochemical Study.*** The Waste Area Group 10 geochemical study used anthropogenic compounds introduced into the Snake River Plain Aquifer from INL Site operations, including Cl-36, sulfate, and nitrate. Isotopic ratios of sulfur and oxygen in sulfate, and nitrogen and oxygen in nitrate are useful tools for delineating the source of these compounds. Radiological constituents, such as Cl-36, were selected because they are very soluble and can be tracked over great distances. Though sulfate and nitrate concentrations are susceptible to redox changes, oxidizing conditions in the aquifer will not change concentrations and isotope signatures. Chlorine-36 and nitrogen and oxygen isotope ratios in nitrate were used to evaluate flow paths from INTEC. Chlorine-36 and sulfur and oxygen isotope ratios in sulfate were used to track plumes from RTC. Sulfur and oxygen isotope ratios in sulfate, along with nitrogen and oxygen isotope ratios in nitrate, were used to evaluate the source of the anion anomaly south of RWMC. Stable isotope data were used because they may be useful for distinguishing sulfate and nitrate plumes farther downgradient from RTC and INTEC as concentrations are diluted to marginally above background.

The next subsection summarizes the Waste Area Group 10 geochemical study, describes analytical methods, and analyzes data in the Waste Area Group 10 Remedial Investigation and Feasibility Study (DOE-ID 2006).

***2.3.4.2 Summary of Waste Area Group 10 Geochemical Study Data.*** This summary integrates results of the Waste Area Group 10 geochemical study with historical data to identify groundwater flow paths and upgradient contaminant influences on aquifer concentrations in the RWMC vicinity.

Stable isotope data are expressed in conventional delta (δ) notation (i.e., per mil [‰], or parts per thousand). The difference in isotope ratios relative to an accepted standard (i.e., Vienna Standard Mean Ocean Water or Canyon Diablo Triolite) can be used to determine processes active in the aquifer and trace the origins of groundwater (Clark and Fritz 1997). The following equation is used:

$$\delta X_{sample} = [(R_{sample} - R_{standard}) / R_{standard}] \times 1{,}000 \qquad (2\text{-}1)$$

where

$\delta X$ = isotope of interest ($\delta^{18}O$, $\delta^{34}S$, or $\delta^{15}N$)

$R$ = ratio of $^{18}O/^{16}O$, $^{15}N/^{14}N$, or $^{34}S/^{32}S$.

---

a. In addition to the completed geochemical studies, Waste Area Group 10 has an I-129 study in progress. Results will be presented in the Waste Area Group 10 2006 annual report.

Previous USGS studies indicated the possibility that facilities upgradient of RWMC may have impacted water quality at RWMC (Mann and Beasley 1994; Beasley, Dixon, and Mann 1998; and Busenberg, Plummer, and Bartholomay 2001). In addition, water-level contour maps also indicated that RWMC is downgradient from RTC and INTEC (see Figure 2-22). Iodine-129, disposed of at INTEC, has been detected at low concentrations in Well USGS-90, which is near RWMC (Mann and Beasley 1994). However, interpreting I-129 data is complicated because I-129 also is present in waste disposed of in the SDA. Technetium-99 is another contaminant that suggests the groundwater at RWMC may be impacted by INTEC. Technetium-99, which was codisposed with I-129 at INTEC, has been detected in the RWMC Production Well at concentrations consistent with historical Tc-99 and I-129 data near INTEC (Mann and Beasley 1994). Again, interpreting the influence from INTEC is complicated because Tc-99, like I-129, also was disposed of at RWMC.

In addition to radiological analytes discussed previously, USGS has mapped concentrations of chlorofluorocarbons in the Snake River Plain Aquifer (Busenberg, Plummer, and Bartholomay 2001). Chlorofluorocarbons were analyzed to estimate the age of groundwater beneath the INL Site. Chlorofluorocarbon concentration trends in the aquifer were identified as potential groundwater flow tracers. The chlorofluorocarbons study indicated a plume of dichlorodifluoromethane originating from INTEC. The pattern of dichlorodifluoromethane concentrations in the aquifer matches that of Cl-36 discussed next and shown in Figure 2-23.

Elevated Cl-36 concentrations from Wells M14S and RWMC Production on the northern and northeastern side of RWMC are similar to concentrations in wells downgradient of INTEC (i.e., M12S, USGS-106, and USGS-104), suggesting groundwater contaminants north of RWMC could have originated at INTEC. In contrast, Cl-36 concentrations in groundwater on the southern side of RWMC are only slightly greater than background and, therefore, do not suggest INTEC as the source. The Cl-36 isotopic ratios downgradient of INTEC in Wells M12S and USGS-106 are three to six times higher than the ratio in Well Middle-1823 downgradient of RTC, implying that INTEC, and not RTC, is the source of the Cl-36 signature at RWMC.

Nitrogen and oxygen isotope data for nitrate yield results similar to Cl-36 data. As Figure 2-24 shows, wells upgradient, but near RWMC (i.e., M12S, USGS-106, M14S, M7S, and RWMC Production), have similar $\delta^{15}N$ and $\delta^{18}O_{nitrate}$ signatures. If groundwater in these wells is affected by INTEC as the Cl-36 data suggest, then $\delta^{15}N$ and $\delta^{18}O_{nitrate}$ concentrations should fall between background values and the value for Well CFA-2. Because $\delta^{15}N$ and the $\delta^{18}O_{nitrate}$ data are indeed between those for Well CFA-2 and background values, the data are consistent with dilution of the INTEC nitrate plume.

Isotopic ratios of sulfur and oxygen in sulfate, $\delta^{34}S$ and $\delta^{18}O_{sulfate}$, were also examined to evaluate the potential impact of upgradient facilities on RWMC. Figure 2-25 shows wells immediately upgradient of RWMC (i.e., M11S, M12S, M13S, M14S, M7S, and RWMC Production) have similar $\delta^{34}S$ and $\delta^{18}O_{sulfate}$ signatures. Based on sulfate data, these wells would appear to be in the same groundwater flow path. This is supported by the fact that Well M12S has tritium concentrations similar to wells closer to RWMC, such as M7S, M14S, and RWMC Production. However, this is complicated by the fact that Wells M11S and M13S have been identified as background locations for RWMC because tritium or Cl-36 have not been detected in either well, and Well M11S has nitrogen and oxygen isotope signatures similar to background.

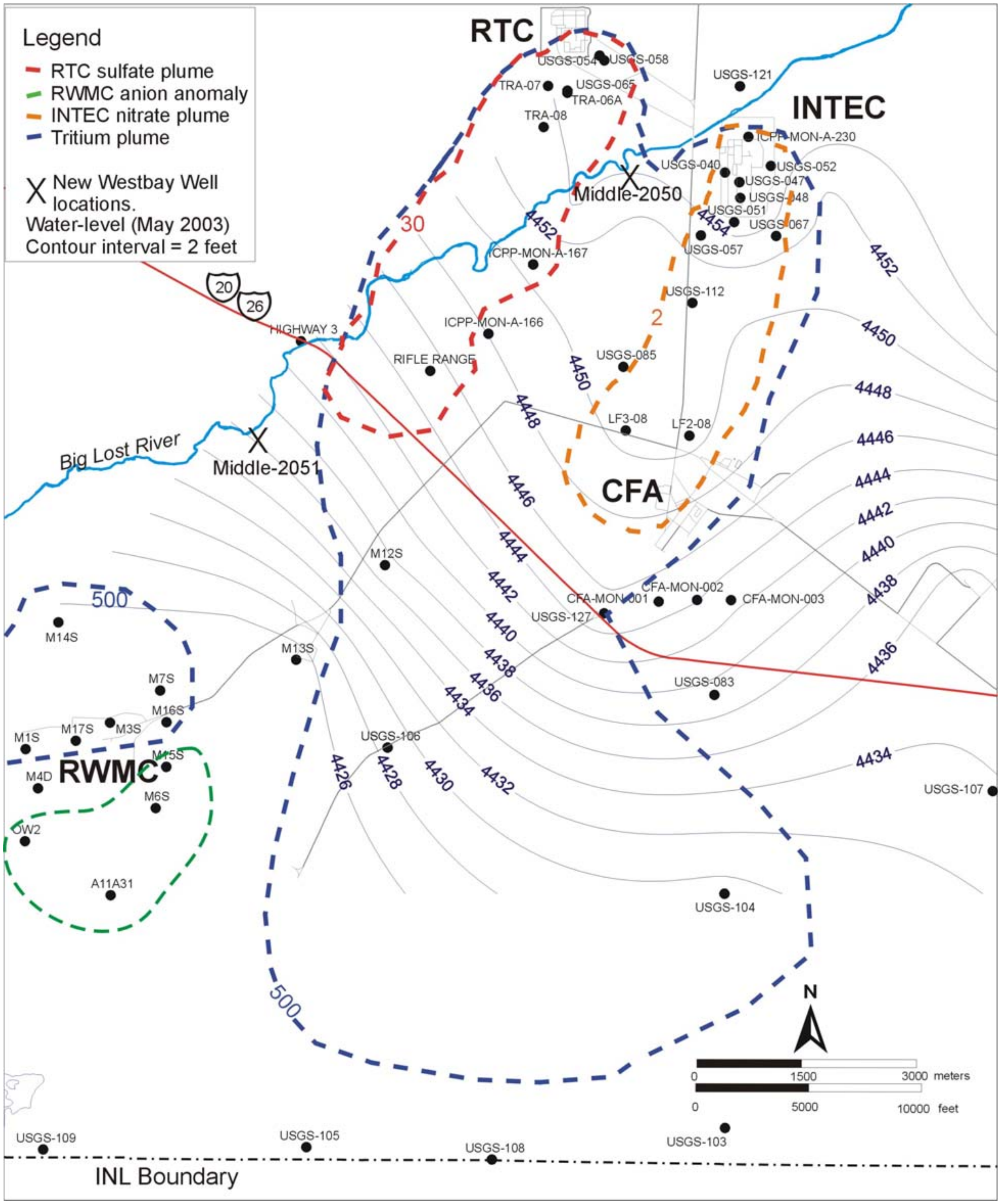



Figure 2-22. Approximate boundaries of select aquifer plumes based on concentrations in 2003 for the Reactor Technology Complex, Idaho Nuclear Technology and Engineering Center, Central Facilities Area, and Radioactive Waste Management Complex areas (data from Roddy and Koeppen 2004).

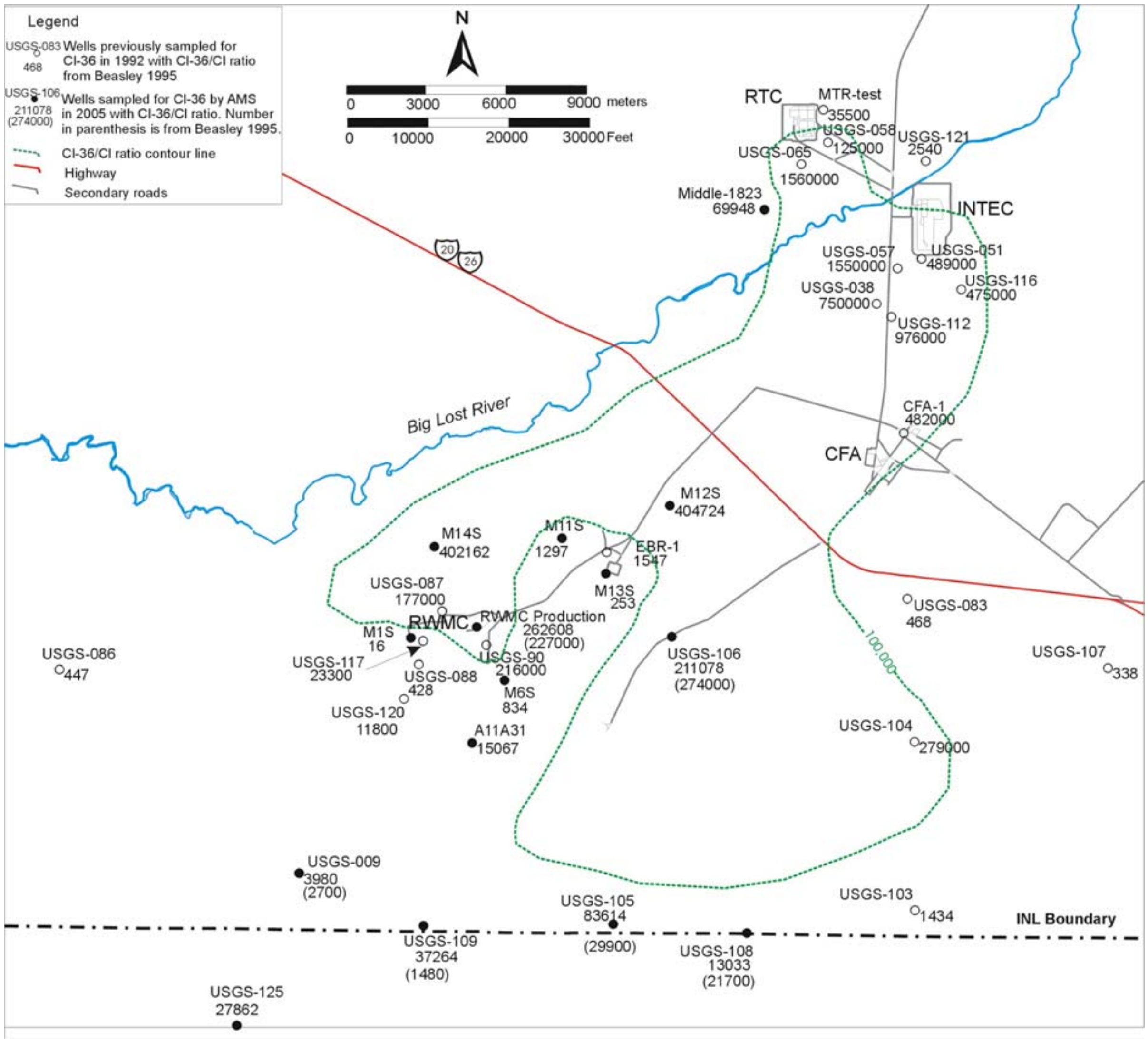



Figure 2-23. Distribution of Cl-36:Cl ratios in the Snake River Plain Aquifer.

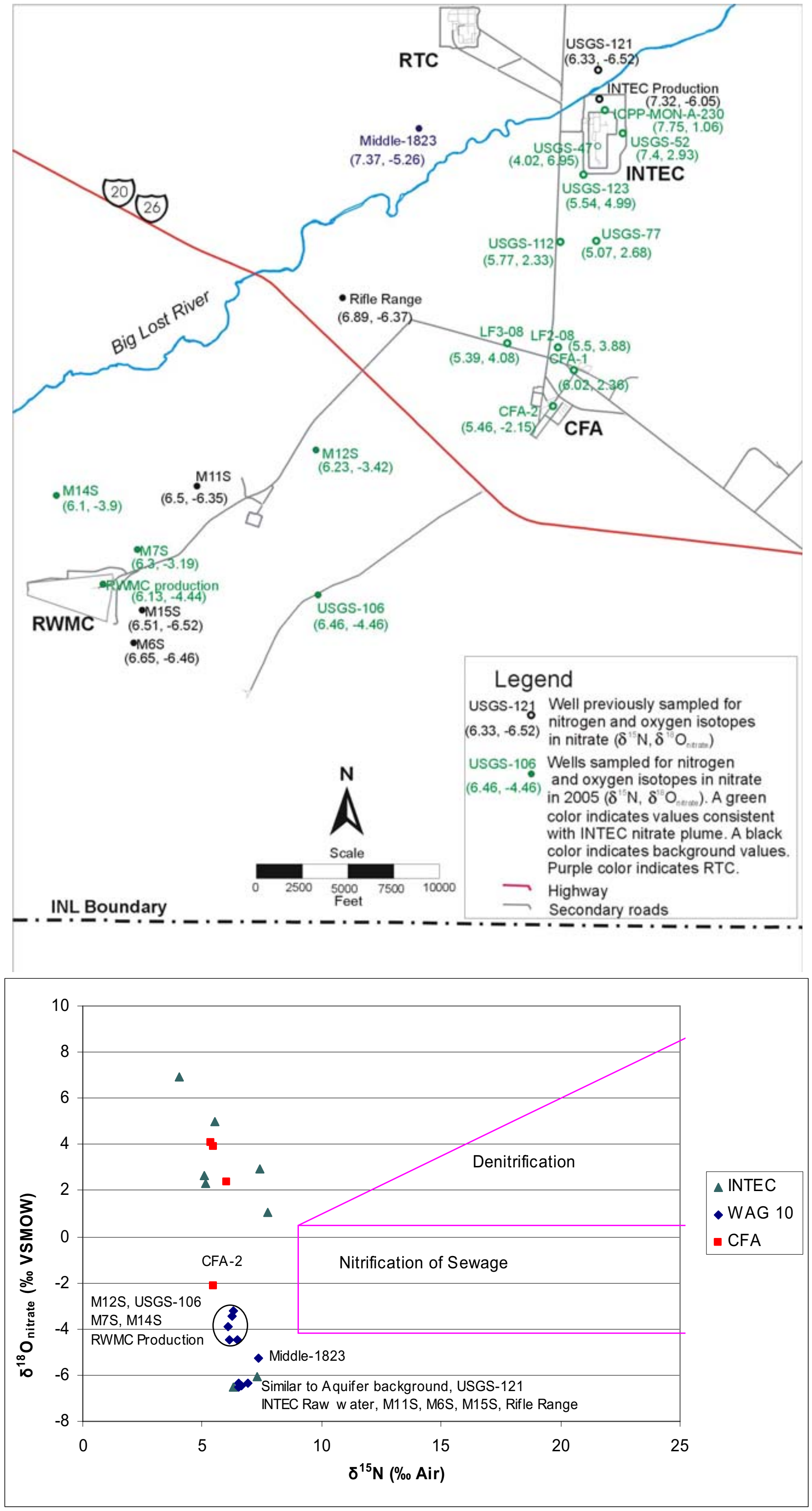



Figure 2-24. Distribution of $\delta^{15}N$ and $\delta^{18}O_{nitrate}$ values in the Snake River Plain Aquifer and plot of $\delta^{15}N$ versus $\delta^{18}O_{nitrate}$.

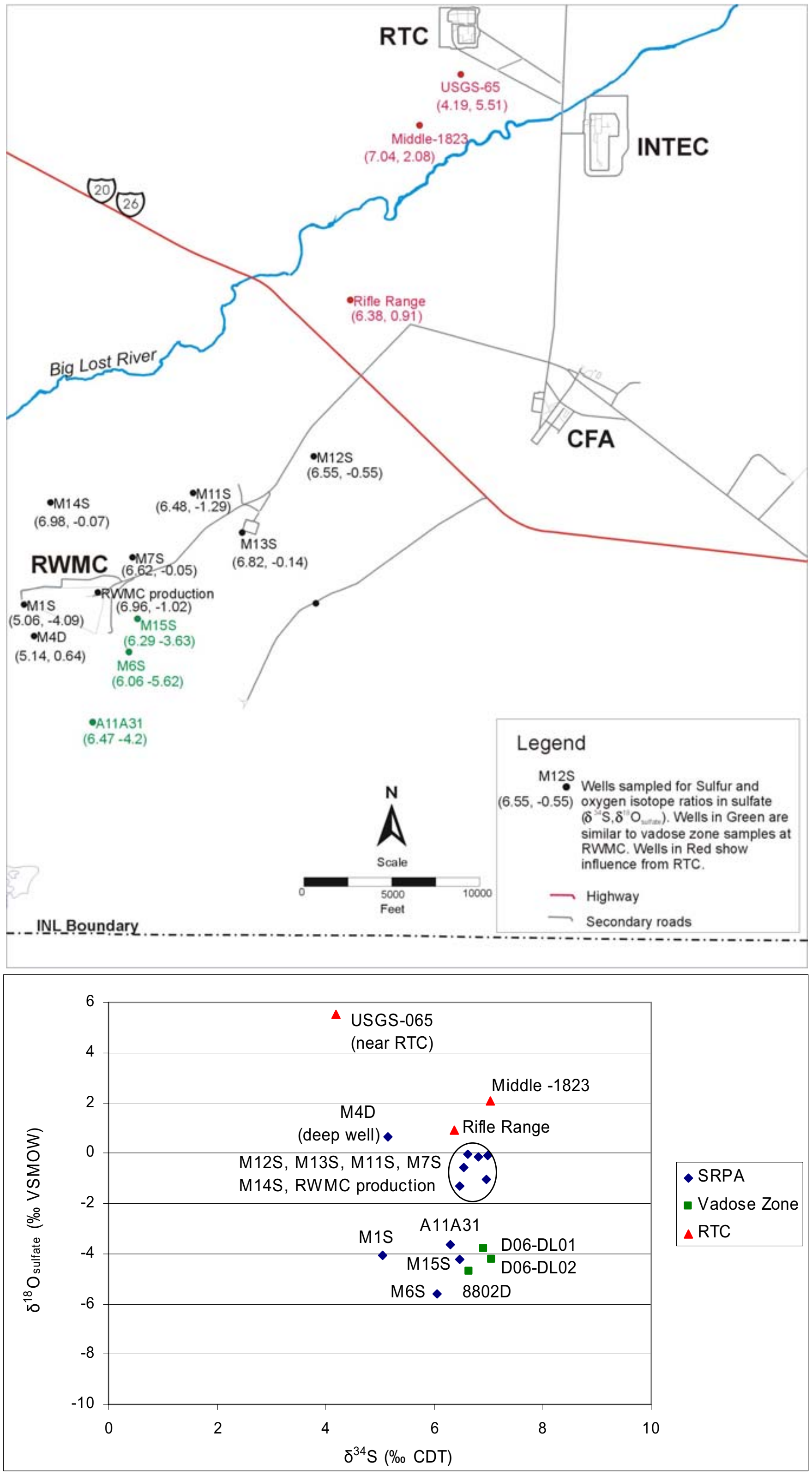



Figure 2-25. Distribution of $\delta^{34}S$ and $\delta^{18}O_{sulfate}$ values in the Snake River Plain Aquifer and plot of $\delta^{34}S$ versus $\delta^{18}O_{sulfate}$.

Concentrations of $\delta^{34}S$ and $\delta^{18}O_{sulfate}$ have been measured in three RWMC vadose zone samples, including perched water from Well 8802D and water from Lysimeters D06-DL01 and D06-DL02. The $\delta^{34}S$ and $\delta^{18}O_{sulfate}$ concentrations from these vadose zone water samples are consistent with concentrations in Wells M15S, M6S, and A11A31, which are southeast and south of RWMC. Because Well M12S has been impacted by INTEC based on I-129, Cl-36, $\delta^{15}N$, and $\delta^{18}O_{nitrate}$ data, and because Wells M7S, M14S, and RWMC Production have $\delta^{34}S$ and $\delta^{18}O_{sulfate}$ signatures similar to Well M12S rather than the vadose zone data, Wells M7S, M14S and RWMC Production likely are impacted by INTEC.

Data for Cl-36, $\delta^{34}S$, $\delta^{18}O_{sulfate}$, $\delta^{15}N$, and $\delta^{18}O_{nitrate}$, are consistent with the premise that INTEC is the source of tritium and other contaminants in groundwater on the northern and eastern sides of RWMC (see Figures 2-23 through 2-25). If INTEC is indeed the source of contamination in the wells near RWMC, then preferential groundwater flow pathways in the aquifer must be bypassing Wells M11S and M13S. Although Wells M11S and M13S are located on the direct flow path from INTEC to RWMC as suggested by water-level contours in Figure 2-22, tritium has not been detected in these wells. Previously, the absence of tritium in Wells M11S, M13S, and EBR-I was interpreted to indicate that the INTEC tritium plume was separate from the RWMC tritium plume (Holdren et al. 2002). The preferential pathway effect appears to occur also south of CFA at Wells USGS-127 and USGS-083 because these wells are in direct pathways of the INTEC tritium plume, but neither well has detected tritium; yet tritium is present in USGS-104 south of these wells. The preferential pathway effect also appears to occur near the new INTEC percolation ponds. Tritium is detected in Well ICPP-MON-A-167 and the Rifle Range Well, but tritium is not detected in Wells ICPP-MON-A-166 located between wells with tritium contamination (Roddy and Koeppen 2004). Because of the potential for preferential flow paths to bypass areas represented by single or multiple wells, the absence of contamination cannot be the sole basis to evaluate the extent or source of contamination.

Carbon tetrachloride from RWMC has been detected in RWMC vicinity wells with tritium contamination, and this association was previously interpreted to indicate that the RWMC tritium plume originates from waste within RWMC because both carbon tetrachloride and tritium can migrate in the vapor phase. However, distribution of carbon tetrachloride in the aquifer forms a circular pattern around RWMC, while tritium occurs only on northern and northeastern sides of RWMC. Carbon tetrachloride forms a pattern around RWMC that is typical of a vapor plume superimposed on local groundwater gradients, but tritium forms no such pattern. This difference suggests that distribution of tritium is controlled primarily by groundwater flow, or perhaps vadose zone leaching, rather than vapor transport.

Stable isotope data also were used to evaluate the source of the anion anomaly (elevated chloride and sulfate) south of RWMC (see Figure 2-22). Possible sources for the anion anomaly south of RWMC are leachate from waste within RWMC, magnesium chloride brine applied to roads at RWMC, or sulfate and chloride plumes from RTC and INTEC. Brine dust suppressant was used at RWMC between 1984 and 1993 and was determined to have migrated in the vadose zone to at least 73.2 m (240 ft) below RWMC (Hull and Bishop 2003). Wells in the anion anomaly (i.e., Wells M6S, M15S, and A11A31) have $\delta^{34}S$ and $\delta^{18}O_{sulfate}$ values closer to values in perched water (i.e., Well 8802D) and lysimeter samples from RWMC that are affected by the brine than values near INTEC or RTC (see Figure 2-25). In contrast, $\delta^{15}N$ and $\delta^{18}O_{nitrate}$ values for Wells M15S and M6S are similar to background values and indicate that nitrate in these wells did not originate from waste buried at RWMC, which should have a $\delta^{15}N$ and $\delta^{18}O_{nitrate}$ signature similar to a manufactured source of nitrate. These nitrate data are supported by the near-background Cl-36:Cl ratio at Well M6S, indicating that elevated anion concentrations probably are not due to migration through waste at RWMC. The $\delta^{15}N$ and $\delta^{18}O_{nitrate}$ values also indicate that leakage from sewage evaporation ponds at RWMC is not the source of the anion anomaly. Literature review and data from INTEC sewage lagoons (Roddy 2005) indicate sewage samples would be expected in the nitrification or denitrification fields shown in Figure 2-24.

***2.3.4.3 Summary and Conclusions.*** Historical data and data collected for the recent Waste Area Group 10 geochemical study support the premise that tritium on the northern side of RWMC is attributable to INTEC. The Cl-36 and stable isotope data also are consistent with an INTEC source, as are previous USGS studies using I-129, Tc-99, and chlorofluorocarbons. However, some wells that are in the INTEC-RWMC flow path, based on water-level data, are inconsistent with this concept because well data are similar to background. Because potential for preferential flow paths to bypass individual wells or areas exists, or because data from individual wells may not be representative of regional conditions, evaluation of the I-129 results by Waste Area Group 10 is necessary to provide additional evidence to support or refute the claim that groundwater from INTEC is impacting RWMC.

Based on stable isotope ratios in sulfate and lack of other contaminants, the anion anomaly on the southern side of RWMC could be from migration of brine dust suppressant historically applied to roads at RWMC. However, sulfur and oxygen isotope data are not definitive. Nitrogen and oxygen isotope data and Cl-36:Cl ratios indicate background values present in Well M6S centered in the anion anomaly. If the source of this anomaly is brine, then data suggest that brine migrated to the aquifer without passing through buried waste at RWMC. This migration is plausible given that brine infiltration primarily occurred from ditches along roads and away from buried waste.

## 2.4 Flora and Fauna

A large percentage of the INL Site is undeveloped land. The original intent for obtaining this expanse of land was to provide a large safety and security buffer between facility areas within the INL Site and between INL Site operations and non-INL Site lands. The general open space at the INL Site still serves this function today. In addition, undeveloped land and its restricted access provide an important habitat for plants and animals and refuge for wildlife. Large numbers of migratory birds of prey and mammals are funneled onto the INL Site because of its location at the mouth of several mountain valleys.

The central core of the INL Site may constitute the largest area of undeveloped and ungrazed sagebrush steppe outside of national park lands in the Intermountain West. In recognition of the importance of this undisturbed area as an ecological field laboratory, DOE designated the INL Site as a National Environmental Research Park in 1975 (Bowman et al. 1984). On July 17, 1999, DOE, the U.S. Fish and Wildlife Service, the Idaho Department of Fish and Game, and the U.S. Bureau of Land Management created the Sagebrush-Steppe Ecosystem Reserve. This reserve comprises 29,947 ha (74,000 acres) of unique habitat in the northwestern portion of the INL Site. This sagebrush environment has a high value to a wide range of wildlife.

Six broad vegetation categories representing nearly 20 distinct habitats have been identified on the INL Site: juniper woodland, native grassland, shrub-steppe off lava, shrub-steppe on lava, modified lands, and wetlands. Nearly 90% of the INL Site is covered by shrub-steppe vegetation, which is dominated by big sagebrush, saltbush, rabbitbrush, and native grasses (INEEL 2001). In addition to predominant sagebrush-steppe communities, small riparian and wetland regions are located along Big Lost River and Birch Creek and have been identified as sensitive biological resource areas within the INL Site. Anderson et al. (1996) compiled a comprehensive list of plant species found on the INL Site; this report also is available through the INL Environmental Surveillance and Research Program Web site http://www.stoller-eser.com (Stoller 2002).

More than 200 vertebrate species (e.g., 37 mammals, 159 birds, nine reptiles, five fish, and one amphibian) have been observed within the INL Site boundaries (Reynolds and Richards 1996). During some years, hundreds of birds of prey and thousands of pronghorn and sage grouse winter at the INL Site. Mule deer and elk also reside at the INL Site. Observed predators include bobcats, mountain lions, badgers, and coyotes. A comprehensive list of animal species found on the INL Site also is available on the INL Environmental Surveillance and Research Program Web site, http://www.stoller-eser.com (Stoller 2002). Bald eagles, classified as a threatened species, are commonly observed at or near the INL Site each winter. Peregrine falcons, which were recently removed from the federal endangered species list, also have been observed within INL Site boundaries. In addition, several other species of concern (e.g., pygmy rabbit, ferruginous hawk, Townsend's big-eared bat, burrowing owl, and loggerhead shrike) either may inhabit or migrate through the area. Some of these species are currently being studied at the INL Site. Threatened and endangered species and other species of concern that may be found on the INL Site are discussed in detail in Section 6.6.2.2 of the Ancillary Basis for Risk Analysis (Holdren et al. 2002) and listed in Table 6-11 of that document.

Flora and fauna at RWMC are representative of species found across the INL Site. Sagebrush-steppe on lava communities with dominant sagebrush and rabbitbrush vegetation comprise nearly 90% of natural cover at Waste Area Group 7. Most waste disposal areas within the SDA have been seeded with grass and are kept mowed. Fauna potentially present at RWMC are those species supported by various vegetation communities that exist at and around the facility. Though not all species have been observed at RWMC, nearly all avian, reptile, and mammalian species found across the INL Site also could be found at RWMC. Larger mammals (e.g., coyotes and antelope) are generally excluded from the SDA and other facility structures by fences, but are occasionally seen on facility grounds. Burrowing rodents (e.g., ground squirrels, voles, and mice) and insects (e.g., harvester ants) are common RWMC inhabitants. No ecologically sensitive areas (i.e., areas of critical habitat) have been identified within RWMC.

## 2.5 Demography

Populations potentially affected by INL Site activities include employees, ranchers who graze livestock in areas on or near the INL Site, hunters on or near the INL Site, residential populations in neighboring communities, travelers along U.S. Highways 20 and 26, visitors at Experimental Breeder Reactor I, and members of the Shoshone-Bannock Tribes, who occasionally visit the INL Site desert for cultural, religious, and educational purposes. As a component of the INL Site, the RWMC area has the same general demographic surroundings.

### 2.5.1 Populations on the Idaho National Laboratory Site

The INL Site work force peaked at 11,961 employees in 1995 but has steadily decreased since then. Approximately 8,000 people currently work at the INL Site (Litus and Shea 2005). Approximately 65%, or 5,300 individuals, commute to the desert site on weekdays, returning home each evening. During weekends, the INL Site maintains a skeleton crew; however, no permanent residents live within its boundaries (Hull 1989). The INL Site work force resides primarily in Bonneville County east of the Site, with Bingham, Bannock, Butte, Jefferson, and Madison Counties and the Shoshone-Bannock Reservation also contributing to worker population (see Figure 2-26).

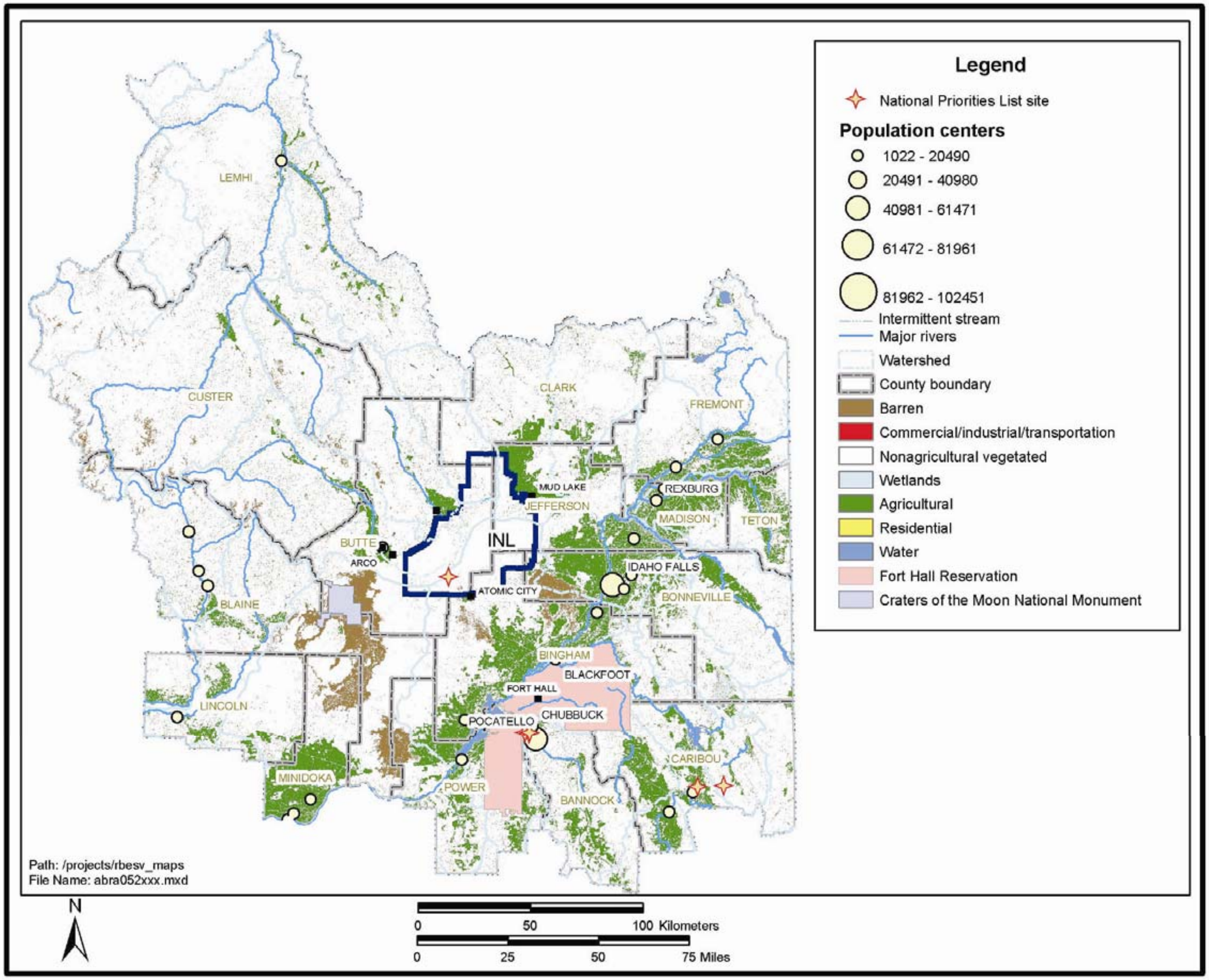



Figure 2-26. Regional human and ecological land use—current state (Litus and Shea 2005).

### 2.5.2 Populations off the Idaho National Laboratory Site

The INL Site is bordered by five Idaho counties: Bingham, Bonneville, Butte, Clark, and Jefferson (see Figure 2-26). Most counties range from 15 to 62 individuals per square mile, making the rural population immediately surrounding the INL Site sparse. Butte County has the lowest population density at 1.3 individuals per square mile. Bonneville County, with the city of Idaho Falls as its population center, has 44.2 individuals per square mile (Litus and Shea 2005). Most of the land bordering the INL Site is open land owned by the U.S. Bureau of Land Management, and therefore, is not available for residential use. Private land bordering the INL Site is used primarily for single-family farms, ranches, and residences.

Major communities include Blackfoot and Shelley in Bingham County; Idaho Falls and Ammon in Bonneville County; Arco in Butte County; Rigby in Jefferson County; and the Fort Hall Indian Reservation in portions of Bingham, Butte, and Power Counties. Several small, agricultural towns, with populations less than 1,000, flank the INL Site boundary. Towns of Arco, Butte City, Moore, and Howe are located west of the INL Site in Butte County, while towns of Monteview, Mud Lake, and Terreton are located east of the INL Site in Jefferson County. Atomic City—the community nearest to the INL Site—is located south of the INL Site in Bingham County on U.S. Highway 20 and 26. See Table 2-4 for population estimates for these counties and selected communities. Detailed statistical information on Idaho is available from the U.S. Census Web site, http://quickfacts.census.gov/qfd/states/16/16019.html/ (Census 2000), or the State of Idaho home page, http://www.state.id.us/ (State of Idaho 2005).

Table 2-4. Population estimates for counties and selected communities surrounding the Idaho National Laboratory Site (Census 2000).

| Location | Population Estimate |
|---|---|
| Bingham County | 42,926 |
| Blackfoot | 10,646 |
| Shelley | 3,885 |
| Clark County | 904 |
| Bonneville County | 87,007 |
| Ammon | 8,623 |
| Idaho Falls | 51,507 |
| Butte County | 2,873 |
| Jefferson County | 20,194 |
| Rigby | 3,035 |

### 2.5.3 Shoshone-Bannock Tribal Interests

The Shoshone-Bannock Tribes of the Fort Hall Indian Reservation is a federally recognized tribe and a sovereign government. The Fort Bridger Treaty of July 3, 1868, Stat. 673 (U.S. Government 1868) secured the Fort Hall Reservation as the permanent homeland of the Shoshone-Bannock peoples. The 1868 Treaty also reserved aboriginal rights to these peoples that extend to areas of unoccupied land in Idaho and surrounding states, allowing access for cultural, political, and economic activities essential to the Tribes' survival. Though the INL Site is occupied land, it does lie within aboriginal territories of the Shoshone-Bannock peoples. The DOE-ID has been proactive in protecting cultural resources at the INL Site and allows tribal members access to areas of cultural and religious significance. For example, in 1994, DOE-ID entered into a Memorandum of Agreement (DOE-ID 2005b) that allows Shoshone-Bannock tribal members unescorted access to the Middle Butte area of the INL Site. Other INL Site areas may be identified for access in the future for cultural, religious, and educational activities. Successive agreements-in-principle, beginning in 1992, have established an ongoing working relationship between the Tribes, DOE-ID, and INL Site contractors to ensure that activities at the INL Site protect tribal health, safety, environment, and cultural resources and address tribal interests in DOE-administered programs (Wilcynski and Tinno). This tribal involvement in INL Site affairs will likely continue.

# 2.6 Land Use

This section summarizes current land use and projections for future land use for the INL Site in general and then, as indicated in subsequent headings, for RWMC specifically.

## 2.6.1 Current Land Use

Approximately 98% of land on the INL Site is open and undeveloped. The INL Site is crossed by several highways, a rail system, and a high-voltage power distribution loop. Public access is restricted by fences, signs, and a number of manned guard gates. Although total land mass of the INL Site is 2,305 $km^2$ (890 $mi^2$), most work is performed within the primary facility areas on the INL Site (Litus and Shea 2005).

Land within the INL Site is administered by DOE and is classified by the U.S. Bureau of Land Management as industrial and mixed-use acreage. The current primary use of INL Site land is to support facility and program objectives. Large tracts of land are reserved as buffer and safety zones around the boundary of the Site, while portions within the central area are reserved for INL Site operations. Remaining land within the core of the reservation, which is largely undeveloped, is used for environmental research and to preserve ecological and cultural resources.

The Snake River Plain Aquifer is the source of all water used at the INL Site. Idaho National Laboratory Site activities withdrew approximately 1.2 billion gal/year in 2004 (INL 2005), more than half of which is ultimately returned to the aquifer, for a net usage of about 420 million gal/year (DOE-ID 1995). In addition to water for drinking and operations at various facilities across the INL Site, water is collected routinely from numerous groundwater monitoring wells, under INL Site environmental monitoring programs, by the USGS and the State of Idaho Oversight Program. Section 4 provides details about groundwater monitoring.

Unrestricted access within INL Site boundaries is limited to public highways and the Experimental Breeder Reactor I National Historic Landmark (see Figure 2-27). State Highways 22, 28, and 33 traverse the northeastern portion of the INL Site, and U.S. Highways 20 and 26 traverse the southern portion.

Grazing permits for INL Site buffer areas are granted by the U.S. Bureau of Land Management. No grazing is permitted within 805 m (2,641 ft) of any primary facility area boundaries. The U.S. Bureau of Land Management is responsible for managing and controlling grazing on the INL Site. The amount of INL Site land used for grazing varies from year to year, but about 60% of the INL Site is open to livestock grazing (see Figure 2-27) (Litus and Shea 2005).

Controlled hunting is permitted on INL Site land in an area restricted to within 805 m (2,641 ft) inside the boundary. Each year, the Idaho Department of Fish and Game and DOE determine whether to allow controlled hunts. The purpose of these hunts is to reduce potential movement of animals off INL Site property and onto private lands where crops may be damaged. To date, hunts have been restricted to pronghorn antelope, elk, and coyotes (Litus and Shea 2005).

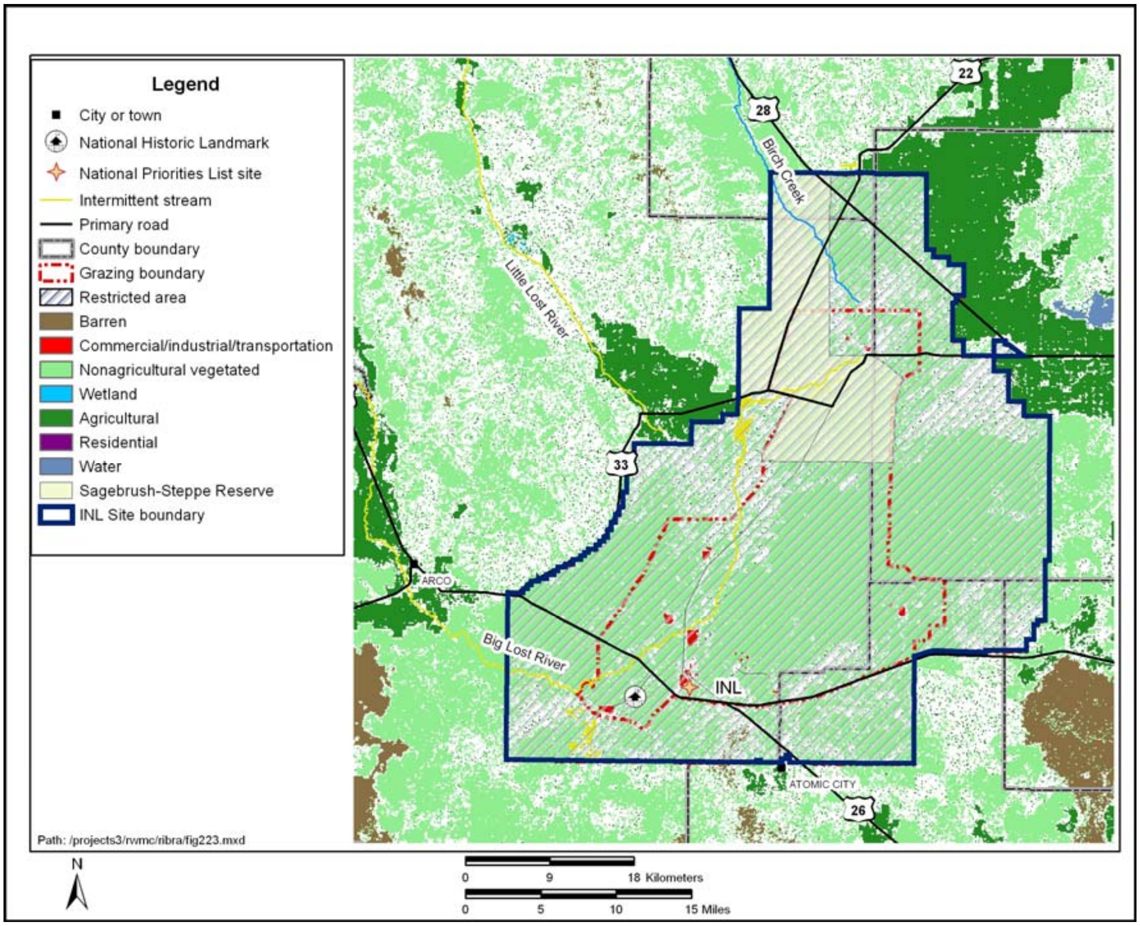



Figure 2-27. Human and ecological land uses at the Idaho National Laboratory Site (adapted from Litus and Shea 2005).

***2.6.1.1 Future Land Use.*** Future land use is addressed in the INL Long-Term Land Use document (DOE-ID 1995), the Long-Range Plan (INEEL 2001), and Summary of INL Cleanup (Litus and Shea 2005). Because future land-use scenarios are uncertain, assumptions were made in the Long-Term Land Use document for defining factors (e.g., development pressure, advances in research and technology, and ownership patterns). The following assumptions were applied to develop forecasts for land use within the INL Site:

- The INL Site will remain under government ownership and control for at least the next 100 years. The boundary is currently static, but may shrink in the future. Portions of the INL Site will be managed beyond 100 years under the Long-Term Stewardship Program currently under development.

- Life expectancy of current and new facilities is expected to range between 30 and 50 years. Deactivation, decontamination, and dismantlement will commence following closure of each facility if new missions for that facility have not been determined.

- No residential development (e.g., housing) will occur within INL Site boundaries within 100 years.

- No new major private developments (residential or nonresidential) will be built in areas adjacent to the INL Site.

Future land (and aquifer) use most likely will remain essentially the same as current use—a research facility within INL Site boundaries, with agriculture and undeveloped land surrounding the INL Site. Other potential, but less likely, land uses within the INL Site include agriculture and return of Site lands to their undeveloped state.

According to Litus and Shea (2005), future land use beyond 100 years has not been defined. After completing the ICP cleanup mission, more than 229,862 ha (568,000 acres) (i.e., 99.9% of the INL Site) is expected to be available for unrestricted use, and approximately 253 ha (626 acres) (i.e., 0.1%) will require restricted access or use beyond 100 years. The DOE, or its successor agency, would be responsible for maintaining institutional controls and conducting environmental monitoring in those areas where residual contamination precludes unrestricted land use.

### 2.6.2 Radioactive Waste Management Complex Current and Future Land Use

Land use at RWMC is limited to industrial applications (i.e., waste management operations and associated support). Waste is received at RWMC for storage, examination, or disposal. Documentation accompanying each waste shipment is reviewed on arrival, and the shipment is visually examined for discrepancies and damage. Radiological surveys are conducted to ensure that radiation and contamination readings meet requirements. Requirements are specified in RWMC waste acceptance criteria (DOE-ID 2005a). If abnormalities are discovered either in waste or in documentation, they are resolved with the waste generator before the waste is formally accepted. Once accepted, waste is transferred to the SDA or the Transuranic Storage Area, as appropriate.

Bechtel BWXT Idaho, LLC, began operations at the Advanced Mixed Waste Treatment Project in May 2004. The project is contracted to retrieve and treat approximately 62,000 $m^3$ (81,092 $yd^3$) of transuranic and alpha LLW currently stored in the Transuranic Storage Area. Operations are expected to be completed no later than December 2018, after which, the facility may undergo closure under the Resource Conservation and Conservation Act (42 USC § 6901 et seq., 1976) and deactivation, decontamination, and decommissioning (Litus and Shea 2005).

Several thousand cubic meters of low-level radioactive waste are disposed of in the SDA each year. Under the Performance Management Plan (DOE-ID 2002), the goal is to continue disposal of contact-handled LLW through the year 2008 and to continue disposal of remote-handled LLW through the year 2009.

Current plans call for discontinuing disposal of LLW in the SDA by the year 2009. A federal task force was chartered to assess viability of this plan, as well as other alternatives for disposal of LLW. Task force recommendations are being reviewed by DOE management to determine whether a revision to the Performance Management Plan (DOE-ID 2002) is warranted. Stored waste at the Transuranic Storage Area will be retrieved and shipped off the INL Site by the year 2018. Because RWMC has not been identified to have a long-term mission, RWMC buildings and infrastructure are anticipated to be removed before the year 2035.

Holdren and Broomfield (2003) state a fundamental assumption for the SDA: "The selected remedy for Operable Unit 7-13/14 will include a surface barrier and institutional controls in perpetuity to manage risk from surface exposure pathways (e.g., external exposure and intrusion by humans, plants, and animals)." The cap design would be selected to effectively inhibit unacceptable ecological exposures and surface exposure pathways for human receptors. Long-term stewardship will be required at RWMC to maintain the cap, monitor the site, and restrict access to residual contamination. These issues will be addressed in the record of decision for Operable Unit 7-13/14.

Future remedial decisions may require expanding current RWMC boundaries to accommodate remedial design and remedial action. During remediation, lay-down areas for construction and site access will be required. In addition, because a cap will be built over the SDA, the RWMC boundary likely will be expanded to allow construction of a cap that extends beyond the current fence line and possibly to establish a buffer zone around the cap.

## 2.7 Cultural Resources

Undisturbed sagebrush rangelands and developed facilities on the INL Site contain thousands of sensitive cultural resources reflecting human use of the region for more than 12,000 years. Sites, such as Aviators' and Middle Butte Caves, Goodale's Cutoff of the Oregon Trail, and Experimental Breeder Reactor I, are relatively well-known examples of the rich human heritage preserved there, and literally thousands more exist. The RWMC has been an important element in the INL Site historical landscape since the early 1950s when construction of the original disposal facility began. The following sections provide an overview of cultural resources at the INL Site, followed by specific resources at RWMC.

### 2.7.1 Regional Cultural Resources Overview

The DOE developed a policy (DOE P 141.1) that helps ensure compliance with the spirit and intent of the legislative mandates that form the basis for managing cultural resources. Through INL Site-specific policies (e.g., Companywide Manual 8), management plans (DOE-ID 2005b), and procedures (MCP-3480), DOE-ID integrates cultural resource management into missions and activities of the INL Site and has created a tailored approach to cultural-resource compliance. The importance of stakeholder involvement in these activities is reflected in two important agreements: one between DOE-ID and the Shoshone-Bannock Tribes ((Wilcynski and Tinno) and a second agreement among DOE-ID and the Idaho State Historic Preservation Office and the Advisory Council on Historic Preservation (DOE-ID 2005b). Archaeological or architectural evaluations and consultation with Native Americans, conducted in advance of all proposed ground disturbance and monitoring of known resources, also help to ensure that continuing research and environmental cleanup and restoration activities minimize effects on sensitive cultural resources.

Cultural resource management has been continuing at the INL Site for more than 40 years (DOE-ID 2005b). To date, just over 8% (i.e., 18,226.49 ha [45,566.23 acres]) of the undeveloped portion of the 2,305-$km^2$ (890-$mi^2$) INL Site has been systematically surveyed for archaeological resources. Local tribal people, whose aboriginal homelands included INL Site areas, have been consulted, and main buildings under DOE-ID jurisdiction have been evaluated. As a result of these efforts, a variety of cultural resources have been identified:

- Archaeological sites
- Contemporary Native American cultural resources
- Historic architectural properties
- Paleontological sites.

More than 2,200 archaeological sites have been identified during surveys at the INL Site. Approximately 90% of this inventory consists of campsites, lithic scatters, and rock features from the prehistoric period (i.e., 12,000 to 150 years ago). A preliminary predictive model suggests that as many as 75,000 additional resources of these types may be undiscovered within the boundaries of the INL Site (Ringe 1995). A smaller proportion of the known archaeological resource inventory includes sites that reflect more recent activities, such as homesteads, old canals and canal construction camps, emigrant trails, stage stops, and railroad sidings from the late 19th and early 20th centuries. Because the INL Site has allowed only limited public access for the past 50 years, many of these cultural resources are remarkably well preserved. More than half of the archaeological resources currently identified at the INL Site are considered to be potentially eligible for nomination to the National Register of Historic Places.

Far less is known about the nature and distribution of Native American cultural resources at the INL Site. However, continuing consultation and cooperation under the Agreement in Principle between DOE-ID and the Shoshone-Bannock Tribes ((Wilcynski and Tinno) have shown that many archaeological sites in the region are ancestral and important to tribal culture. Natural land forms and native plants and animals of the northeastern Snake River Plain also are of sacred and traditional importance and, though rare, human burials are of special concern. Investigations of these types of cultural resources on the INL Site are continuing, and again, because a large portion of the INL Site area remains undeveloped, cultural resources of this type are largely undisturbed.

Historically, significant cultural resources are located in developed portions of the INL Site. These resources include buildings, structures, and objects that have made significant contributions to the broad patterns of American history through their association with World War II, the Cold War, and important advances in science and technology (Stacey 2000). Results from a 1997 architectural survey of DOE-ID buildings indicated that at least 200 of over 500 buildings surveyed were potentially eligible for nomination to the National Register of Historic Places, either individually or as contributing elements of a historic district (Arrowrock 2003). In addition, remaining buildings and structures contribute to the overall INL Site historic landscape. As mentioned in Section 2.1, one INL Site nuclear facility, the Experimental Breeder Reactor I, is listed as a national historic landmark.

A relatively small number of paleontological sites is included in the cultural resource inventory of the INL Site. Though these resources do not reflect human activity in the region, they often provide important background information on climate and the environment. Approximately 25 sites of this type have been identified, including 17 with vertebrate remains (DOE-ID 2005b).

### 2.7.2 Local Cultural Resources

All four major types of INL Site cultural resources (i.e., archaeological sites, contemporary Native American cultural resources, historic architectural properties, and paleontological sites) have been identified in the RWMC area during previous cultural resource investigations. Ten major archaeological survey projects identified an inventory of 13 potentially significant prehistoric sites within a 200-m (656-ft) -wide zone surrounding the fenced perimeter of the facility and more than 80 additional archaeological resources in the surrounding area. Paleontological remains have been identified in excavations within the facility. Shoshone-Bannock tribal members have been consulted about additional resources of Native American concern during at least two tours of the area. In addition, as a result of architectural surveys of 55 DOE-ID-administered buildings within the developed portion of RWMC, three buildings have been identified as potentially eligible for nomination to the National Register of Historic Places. Additional details on these resources are given in the following paragraphs.

Beginning in 1984, a succession of surveys (i.e., 1984, 1985, 1987, 1988, 1990, 1993, and 1999) by archaeologists from Idaho State University revealed a number of prehistoric archaeological sites in the RWMC area. Systematic surveys conducted by the INL Cultural Resource Management Office in 1993 and 1999 further established the archaeological sensitivity of the area (DOE-ID 2005b). The current known inventory of archaeological resources near RWMC includes items from the prehistoric period (i.e., 12,000 to 150 years ago), such as isolated artifacts, stone tool modification sites, hunting camps, extended camps, and stone features, as well as items from historic times (i.e., 150 to 50 years ago), such as Oregon Trail remnants, stage stations, homesteads, early town sites, and canals. Nearly all archaeological resources near RWMC exhibit potential for future scientific research and are, thus, potentially eligible for nomination to the National Register of Historic Places.

To mitigate the effects of limited expansion of RWMC-related activities, research test excavations have been completed at three of the archaeological sites very near the RWMC perimeter fence (DOE-ID 2005b). As a result of this work and consultation with the Idaho State Historic Preservation Office, one prehistoric archaeological site has been determined ineligible for nomination to the National Register of Historic Places. The 12 additional sites located within 200 m (656 ft) of the facility fence remain unevaluated and are considered potentially eligible for nomination. This also is true of the more than 80 archaeological resources located in a wider perimeter around the facility. Given the high degree of ground disturbance within the fenced perimeter of RWMC, the Idaho State Historic Preservation Office has agreed that little potential exists for undisturbed archaeological materials and has recommended clearance for continuing and future ground disturbance without additional consultation. However, all work at the INL Site is subject to strong stop-work stipulations if cultural materials are discovered during project implementation (MCP-553).

Since construction began in the early 1950s, RWMC has filled an important role in INL Site history and occupied a prominent place in the overall historic landscape. Architectural surveys have revealed two existing buildings that may be eligible for nomination to the National Register of Historic Places because of their association with waste management and remediation activities (Arrowrock 2003):

- WMF-601—Radiological Control Field Office
- WMF-610—Advanced Mixed Waste Treatment Project Waste Examination Plant (formerly the Stored Waste Examination Pilot Plant).

Vertebrate paleontological remains have been reported in three separate instances during excavations within deep sediment that underlie RWMC facilities (DOE-ID 2005b). All are Pleistocene in age (i.e., 3 million to 10,000 years ago) and are not associated with cultural artifacts. Two of the finds—a horse metapodial and an unidentified megafaunal element—were discovered 4.6 to 4.9 m (15 to 16 ft) below ground surface, while a sandy lens approximately 1 to 2.4 m (3 to 8 ft) below ground surface yielded mammoth remains.

Shoshone-Bannock tribal members, as stakeholders concerned about preserving cultural resources at the INL Site, have toured the RWMC area on at least two occasions.[b,c] Tribal members have clearly indicated that all archaeological sites in the RWMC vicinity are of tribal importance; they have also expressed cultural interest in plant and animal populations of the area.

---

b. Tour of RWMC and Advanced Mixed Waste Treatment Project facility areas by Shoshone-Bannock tribal members, March 11, 1998, Tour No. 035-98, Public Affairs, Idaho National Engineering and Environmental Laboratory.

c. Tour of RWMC area, INTEC, and Fort Hall by State and Tribal Governments Working Group, October 21, 1999, Tour No. 155-99, Public Affairs, Idaho National Engineering and Environmental Laboratory.

## 2.8 References


56 FR 50634, 1991, "Sole Source Designation of the eastern Snake River Plain Aquifer, Southern Idaho; Final Determination, U.S. Environmental Protection Agency," *Federal Register*.

42 USC § 6901 et seq., 1976, "Resource Conservation and Recovery Act of 1976 (Solid Waste Disposal Act)," *United States Code*.

Anderson, J. E., K. T. Ruppel, J. M Gennon, K. E. Holte, and R. C. Rope, 1996, *Plant Communities, Ethnoecology, and Flora of the Idaho National Engineering Laboratory*, ESRF-005, Environmental Science and Research Foundation Report Series.

Anderson, S. R. and B. D. Lewis, 1989, *Stratigraphy of the Unsaturated Zone at the Radioactive Waste Management Complex, Idaho National Engineering Laboratory, Idaho*, U.S. Geological Survey Water Resources Investigations Report 89-4065, DOE/ID-22080. U.S. Department of Energy Idaho Operations Office.

Anderson, S. R., M. J. Liszewski, and D. J. Ackerman, 1996, *Thickness of Surficial Sediment at and Near the Idaho National Engineering Laboratory, Idaho*, U.S. Geological Survey Open-File Report 96-330, U.S. Geological Survey.

Arrowrock Group, 2003, *The Idaho National Environmental and Engineering Laboratory A Historic Context and Assessment Narrative and Inventory*, INEEL/EXT-97-01021, Rev. 1, prepared for the U.S. Department of Energy Idaho Operations Office.

Bargelt, R. J., C. A. Dicke, J. M. Hubbell, M. Paarmann, D. Ryan, R. W. Smith, and T. R. Wood, 1992, *Summary of RWMC Investigations Report*, EGG-WM-9708, Rev. 0, Idaho National Engineering Laboratory.

Barraclough, J. T., J. B. Robertson, V. J. Janzer, and L. G. Saindon, 1976, *Hydrology of the Solid Waste Burial Ground, as Related to the Potential Migration of Radionuclides, at the Idaho National Engineering Laboratory*, USGS Open-File Report 76-471, IDO 22056, prepared by the U.S. Geological Survey for the U.S. Energy Research and Development Administration.

Beasley, T. M., 1995, *The Inventory of Site-Derived Chlorine-36 in the Snake River Plain Aquifer, Idaho National Engineering Laboratory, Idaho*, EML-567, U.S. Department of Energy, February 1995.

Beasley, T. M., P. R. Dixon, and L. J. Mann, 1998, "$^{99}$Tc, $^{236}$U, and $^{237}$Np in the Snake River Aquifer at the Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho," *Environmental Science and Technology*, Vol. 32, No. 24, pp. 3875–3881.

Becker, B. H., T. A. Bensen, C. S. Blackmore, D. E. Burns, B. N. Burton, N. L. Hampton, R. M. Huntley, R. W. Jones, D. K. Jorgensen, S. O. Magnuson, C. Shapiro, and R. L. Van Horn, 1996, *Work Plan for Operable Unit 7-13/14 Waste Area Group 7 Comprehensive Remedial Investigation/Feasibility Study*, INEL-95/0343, Rev. 0, Idaho National Engineering Laboratory.

Bennett, C. M., 1986, *Capacity of the Diversion Channel Below the Flood-Control Dam on the Big Lost River at the Idaho National Engineering Laboratory*, U.S. Geological Survey Water-Resources Investigations Report 86-4204, U.S. Geological Survey.

Bishop, C. W., 1998, *Soil Moisture Monitoring Results at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory, FY-96, FY-95, and FY-94*, INEEL/EXT-98-00941, Idaho National Engineering and Environmental Laboratory.

Bowman, A. L., W. F. Downs, K. S. Moor, and B. F. Russell, 1984, *INEL Environmental Characterization Report*, *Volume II: Appendices A–C,* EGG-NPR-6688, Rev. 0, Idaho National Engineering Laboratory.

Burgess, J. D., B. D. Higgs, and T. R. Wood, 1994, *Waste Area Group 7 Groundwater Pathway Track 2 Summary Report*, EGG-ER-10731, Idaho National Engineering Laboratory.

Busenberg, E., L. N. Plummer, and R. C. Bartholomay, 2001, *Estimated Age and Source of the Young Fraction of Ground Water at the Idaho National Engineering and Environmental Laboratory*, U.S. Geological Survey Water-Resources Investigations Report 01-4265, U.S. Geological Survey.

Case, Marilyn J., Arthur S. Rood, James M. McCarthy, Swen O. Magnuson, Bruce H. Becker, and Thomas K. Honeycutt, 2000, *Technical Revision of the Radioactive Waste Management Complex Low-Level Waste Radiological Performance Assessment for Calendar Year 2000,* INEEL/EXT-2000-01089, Idaho National Engineering and Environmental Laboratory.

Casper, Jason L., Hopi Salomon, and Gail L. Olson, 2006, *Field Sampling Plan for Lysimeter and Perched Water Monitoring of Operable Unit 7-13/14*, INEEL/EXT-2000-00714, Rev. 3, Idaho National Laboratory, Idaho Cleanup Project.

Cecil, L. D., J. R. Pittman, T. M. Beasley, R. L. Michel, P. W. Kubik, P. Sharma, U. Fehn, and H. Gove, 1992, "Water Infiltration Rates in the Unsaturated Zone at the Idaho National Engineering Laboratory Estimated from Chlorine-36 and Tritium Profiles, and Neutron Logging," *Proceedings of the 7th International Symposium on Water-Rock Interaction*, *Park City, UT*, WRI-7, Rotterdam: Balkema.

Census, 2000, *Profiles of General Demographic Characteristics, 2000, Idaho*, URL: http://quickfacts.census.gov/qfd/states/16/16019.html/, Census Population and Housing, U.S. Department of Commerce, Economics and Statistics Administration, and U.S. Census Bureau, Web site last visited August 25, 2005.

Chatwin, T. D., A. D. Coveleski, K. J. Galloway, J. M. Hubbell, R. M. Lugar, G. E. Mathern, O. R. Perry, A. J. Sondrup, and S. N. Stanisich, 1992, *Final Work Plan for the Organic Contamination in the Vadose Zone, Operable Unit 7-08, Focused Remedial Investigation/Feasibility Study*, EGG-WM-10049, Rev. 1, Idaho National Engineering Laboratory.

Clark, I. D. and P. Fritz, 1997, *Environmental Isotopes in Hydrogeology*, Boca Raton: CRC Press, p. 328.

Clawson, K. L., G. E. Start, and N. R. Ricks, 1989, *Climatography of the Idaho National Engineering Laboratory 2nd Edition*, DOE/ID-12118, U.S. Department of Energy Idaho Operations.

Clawson, K. L., N. Hukari, and N. R. Ricks. 2005, *Climatology of the Idaho National Laboratory. 3rd Edition*, U. S. Department of Commerce, National Oceanic and Atmospheric Administration Environmental Research Laboratories, Air Resources Laboratory Field-Research Division.

Dechert, Thomas V., Paul A. McDaniel, and Anita L. Falen, 1994, *Aggradational and Erosional History of the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory*, EGG-WM-11049, Idaho National Engineering Laboratory.

DOE, 1981, *Draft Environmental Impact Statement, Long-Term Management of Defense High-Level Radioactive Waste, Idaho Chemical Processing Plant,* DOE/EIS-0074D, U.S. Department of Energy.

DOE P 141.1, 2001, "Department of Energy Management of Cultural Resources," U.S. Department of Energy.

DOE-ID, 1995, *Long-Term Land Use Future Scenarios for the Idaho National Engineering Laboratory*, DOE/ID-10440, U.S. Department of Energy Idaho Operations Office.

DOE-ID, 2002, *Environmental Management Performance Management Plan for Accelerating Cleanup of the Idaho National Engineering and Environmental Laboratory*, DOE/ID-11006, U.S. Department of Energy Idaho Operations Office.

DOE-ID, 2004, *Idaho National Engineering and Environmental Laboratory Operable Unit 10-08, Sitewide Groundwater Model Work Plan*, DOE/NE-ID-11188, Rev. 0, U.S. Department of Energy Idaho Operations Office.

DOE-ID, 2005a, *Idaho National Engineering and Environmental Laboratory Waste Acceptance Criteria*, DOE/ID-10381, Rev. 21, U.S. Department of Energy Idaho Operations Office.

DOE-ID, 2005b, *Idaho National Engineering and Environmental Laboratory Cultural Resource Management Plan*, DOE/ID-10997, Rev. 1, U.S. Department of Energy Idaho Operations Office.

DOE-ID, 2006, *Waste Area Group 10, Operable Unit 10-08, Remedial Investigation/Feasibility Study Annual Status Report for Fiscal Year 2005*, DOE/ID-11274, Rev. 0, U.S. Department of Energy Idaho Operations Office

Dooley, Kirk and Brian D. Higgs, 2003, *End of Well Reports for the OU 7-13/14 Fiscal Year 2000 Well Drilling Project at the Radioactive Waste Management Complex*, INEEL/EXT-2000-00400, Rev. 0, Idaho National Engineering and Environmental Laboratory.

Dunnivant, F. M., M. E. Newman, C. W. Bishop, D. Burgess, J. R. Giles, B. D. Higgs, J. M. Hubbell, E. Neher, G. T. Norrell, M. C. Pfiefer, I. Porro, R. C. Starr, and A. H. Wylie, 1998, "Water and Radioactive Tracer Flow in a Heterogeneous Field-Scale System," *Ground Water*, Vol. 36, pp. 949–958.

Gorman, V. W. and R. C. Guenzler, 1983, *The 1983 Borah Peak Earthquake and INEL Structural Performance*, EGG-EA-6501, Idaho National Engineering Laboratory.

Greely, R., 1982, "The Style of Basaltic Volcanism in the Eastern Snake River Plain, Idaho," *Cenozoic Geology of Idaho, Idaho Bureau of Mines and Geology Bulletin*, Idaho Bureau of Mines and Geology.

Hackett, W. R., J. Pelton, and C. Brockway, 1986, *Geohydrologic Story of the eastern Snake River Plain and the Idaho National Engineering Laboratory*, Administrative Record No. 8405, Idaho National Engineering Laboratory.

Hackett, W. R. and R. P. Smith, 1992, "Quaternary Volcanism, Tectonics, and Sedimentation in the Idaho National Engineering Laboratory Area," *Field Guide to Geologic Excursions in Utah and Adjacent Areas of Nevada, Idaho, and Wyoming, Geological Society of America Rocky Mountain Section Guidebook,* Utah Geological Survey Miscellaneous Publication 92-3, Utah Geological Survey, pp. 1–18.

Hackett, W. R., M. Anders, and R. C. Walter, 1994, "Preliminary Stratigraphic Framework of Rhyolites from Corehole WO-2, Idaho National Engineering Laboratory: Caldera-Related, Late-Tertiary Silicic Volcanism of the eastern Snake River Plain," *International Symposium on the Observation of the Continental Crust Through Drilling*, *VIIth,* Santa Fe, New Mexico.

Hackett, W. R., J. A. Tullis, R. P. Smith, S. J. Miller, T. V. Dechert, P. A. McDaniel, and A. L. Falen, 1995, *Geologic Processes in the RWMC Area, Idaho National Engineering Laboratory: Implications for Long Term Stability and Soil Erosion at the Radioactive Waste Management Complex,* INEL-95/0519, Idaho National Engineering Laboratory.

Hackett, W. R., R. P. Smith, and S. Khericha, 2002, "Volcanic Hazards of the Idaho National Engineering and Environmental Laboratory, Southeast Idaho," *Tectonic and Magmatic Evolution of the Snake River Plain Volcanic Province, Idaho*, Idaho Geological Survey Bulletin, Vol. 30, pp. 461–482.

Holdren, K. Jean, Bruce H. Becker, Nancy L. Hampton, L. Don Koeppen, Swen O. Magnuson, T. J. Meyer, Gail L. Olson, and A. Jeffrey Sondrup, 2002, *Ancillary Basis for Risk Analysis of the Subsurface Disposal Area*, INEEL/EXT-02-01125, Rev. 0, Idaho National Engineering and Environmental Laboratory.

Holdren, K. Jean and Barbara J. Broomfield, 2003, *Second Revision to the Scope of Work for the Operable Unit 7-13/14 Waste Area Group 7 Comprehensive Remedial Investigation/Feasibility Study*, INEL-95/0253, Rev. 2, Idaho National Engineering and Environmental Laboratory.

Holdren, K. Jean and Barbara J. Broomfield, 2004, *Second Addendum to the Work Plan for the OU 7-13/14 Waste Area Group 7 Comprehensive Remedial Investigation/Feasibility Study*, DOE/ID-11039, U.S. Department of Energy Idaho Operations Office.

Hubbell, J. M., 1990, *Perched Ground Water at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory*, EGG-ER-8779, Rev. 0, Idaho National Engineering Laboratory.

Hubbell, J. M., 1992, *Perched Water at the Radioactive Waste Management Complex*, VVED-ER-098, Rev. 0, Idaho National Engineering Laboratory.

Hubbell, J. M., 1993, "Perched Groundwater Monitoring in the Subsurface Disposal Area of the Radioactive Waste Management Complex," ER&WM-EDF-002293, Idaho National Engineering Laboratory.

Hubbell, J. M., 1995, *Perched Groundwater Monitoring in the Subsurface Disposal Area of the Radioactive Waste Management Complex, Idaho, FY-94*, INEL-95/149, Idaho National Engineering Laboratory.

Hubbell, J. M., L. C. Hull, T. G. Humphrey, B. F. Russell, J. R. Pittman, and K. M. Cannon, 1985, *Annual Progress Report: FY-1985—Subsurface Investigation Program at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory*, DOE/ID-10136, U.S. Department of Energy Idaho Operations Office.

Hubbell, J. M., L. C. Hull, T. G. Humphrey, B. F. Russell, J. R. Pittman, and P. R. Fischer, 1987, *Annual Progress Report FY-1986: Subsurface Investigations Program at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory*, DOE/ID-10153, Rev. 0, U.S. Department of Energy Idaho Operations Office.

Hubbell, J. M., E. D. Mattson, J. B. Sisson, and D. L. McElroy, 2002, "Water Potential Response in a Fractured Basalt from Infiltration Events," *Evaluation and Remediation of Low Permeability and Dual Porosity Environments*, ASTM 1415, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

Hubbell, J. M., M. J. Nicholl, J. B. Sisson, and D. L. McElroy, 2004, "Application of a Darcian Approach to Estimate Liquid Flux in a Deep Vadose Zone," *Vadose Zone Journal*, Vol. 3, pp. 560–569.

Hubbell, Joel M., Carolyn W. Bishop, Mike J. Rohe, and Vivian G. Schultz, 2005, *Moisture-Monitoring Program at the Subsurface Disposal Area for Fiscal Year 2004,* ICP/EXT-05-00829, Idaho National Laboratory, Idaho Cleanup Project.

Hull, L. C., 1989, *Conceptual Model and Description of the Affected Environment for the TRA Warm Waste Pond (Waste Management Unit, TRA-03)*, EGG-ER-8644, Idaho National Engineering Laboratory.

Hull, Larry C. and Carolyn W. Bishop, 2003, *Fate of Magnesium Chloride Brine Applied to Suppress Dust from Unpaved Roads at the INEEL Subsurface Disposal Area*, INEEL/EXT-01-01173, Rev. 0, Idaho National Engineering and Environmental Laboratory.

Humphrey, Thomas G. and Fred H. Tingey, 1978, *The Subsurface Migration of Radionuclides at the Radioactive Waste Management Complex*, TREE-1171, Rev. 0, Idaho National Engineering Laboratory.

ICC, 2000, *International Building Code*, International Code Council.

ICP, 2004, *End of Well Report for Waste Area Group 7 South 1898*, ICP/EXT-04-00206, Idaho National Engineering and Environmental Laboratory, Idaho Completion Project.

INEEL, 2000, *Recomputation of the Seismic Hazard at the Idaho National Engineering and Environmental Laboratory*, INEEL/EXT-99-00786, Idaho National Engineering and Environmental Laboratory.

INEEL, 2001, *Infrastructure Long-Range Plan*, INEEL/EXT-2000-01052, Rev. 0, Idaho National Engineering and Environmental Laboratory.

INEL, 1988, *RCRA Facility Investigation Work Plan, Vol. 1,* EGG-WM-8219, Rev. 1, Idaho National Engineering Laboratory.

INEL, 1990, *Assessment of Potential Volcanic Hazards for New Production Reactor Site at the Idaho National Engineering Laboratory*, EGG-NPR-10624, Idaho National Engineering Laboratory.

INEL, 1996, Site-*Specific Probabilistic Seismic Hazard Analyses for the Idaho National Engineering Laboratory*, *Volume I Final Report*, INEL-95/0536, Idaho National Engineering Laboratory.

INL, 2005, *Idaho National Laboratory Strategic Plan—Leading the Renaissance in Nuclear Energy*, INL/EXT-05-00739, Idaho National Laboratory.

Irving, J. S., 1993, *Environmental Resource Document for the Idaho National Engineering Laboratory*, EGG-WMO-10279, Idaho National Engineering Laboratory.

Jackson, S. M., 1985, "Acceleration Data from the 1983 Borah Peak, Idaho, Earthquake Recorded at the Idaho National Engineering Laboratory," *Proceedings of Workshop XXVIII On the Borah Peak, Idaho, Earthquake*, *Volume A Convened under Auspices of National Earthquake Prediction and Hazard Programs, 3 - 6 October 1984,* U.S. Geological Survey Open-File Report 85-290, U.S. Geological Survey, pp. 385-400.

Jackson, S. M., I. G. Wong, G. S. Carpenter, D. M. Anderson, and S. M. Martin, 1993, "Contemporary Seismicity in the eastern Snake River Plain, Idaho, Based on Microearthquake Monitoring," *Bulletin of the Seismological Society of America*, Vol. 83, No. 3, pp. 680–695.

Jolley, Wendell, 2003, "Fiscal Year 2003 Pumping Test Results from Wells Located at the Radioactive Waste Management Complex," EDF-3777, Rev. 0, Idaho National Engineering and Environmental Laboratory.

Keck, K. N., 1995, *SDA Surface Water Description and Data,* INEL-95/119, EDF-ER-WAG7-66, Idaho National Engineering Laboratory.

Kjelstrom, L. C. and C. Berenbrock, 1996, *Estimated 100-Year Peak Flows and Flow Volumes in the Big Lost River and Birch Creek at the Idaho National Engineering Laboratory, Idaho*, U.S. Geological Survey Water-Resources Investigations Report 96-4163, U.S. Geological Survey.

Koslow, K. N. and D. H. Van Haaften, 1986, *Flood Routing Analysis for a Failure of Mackay Dam*, EGG-EP-7184, Idaho National Engineering Laboratory.

Kuntz M. A., H. R. Covington, and L. J. Schorr, 1992, "An Overview of Basaltic Volcanism of the Eastern Snake River Plain, Idaho," *Regional Geology of Eastern Idaho and Western Wyoming,* Geological Society of America Memoir, Vol. 179, pp. 227-267.

Kuntz, M. A., B. Skipp, M.A. Lanphere, W. E. Scott, K. L. Pierce, G. B. Dalrymple, D. E. Champion, G. F. Embree, W. R. Page, L. A. Morgan, R. P. Smith, W. R. Hackett, and D. W. Rodgers, 1994, *Geologic Map of the Idaho National Engineering Laboratory and Adjoining Areas, Eastern Idaho, Miscellaneous Investigation Map, I-2330, 1:100,000 scale*, U.S. Geological Survey.

Kuntz, M. A., S. A. Anderson, D. E. Champion, M. A. Lanphere, and D. J. Grunwald, 2002, "Tension Cracks, Eruptive Fissures, Dikes, and Faults Related to Late Pleistocene-Holocene Basaltic Volcanism and Implications for the Distribution of Hydraulic Conductivity in the eastern Snake River Plain, Idaho," *Special Paper 353: Geology, Hydrogeology, and Environmental Remediation: Idaho National Engineering and Environmental Laboratory, eastern Snake River Plain, Idaho,* Geological Society of America, pp. 111–133, URL: http://www.gsajournals.org/gsaonline/?request=get-abstract&doi=10.1130%2F0-8137-2353-1(2002)353%3C111:TEAFRT%3E2.0.CO%3B2, Web page last visited May 2006.

Lamke, R. D., 1969, *Stage-Discharge Relations on Big Lost River within National Reactor Testing Station, Idaho*, U.S. Geological Survey Open-File Report, IDO-22050, U.S. Atomic Energy Commission.

Laney, P. T., S. C, Minkin, R. G. Baca, D. L. McElroy, J. M. Hubbell, L. C. Hull, B. F. Russell, G. J. Stormberg, and J. T. Pittman, 1988, *Annual Progress Report: FY-1987: Subsurface Investigations Program at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory,* DOE/ID-10183, U. S. Department of Energy Idaho Operations Office.

Litus, Marty and Jerry P. Shea, 2005, *Summary of Cleanup at the Idaho National Laboratory Site*, ICP/EXT-05-00806, Rev. 0, Idaho National Laboratory, Idaho Completion Project.

Magnuson, S. O., 1993, *A Simulation Study of Moisture Movement in Proposed Barriers for the Subsurface Disposal Area*, EGG-WM-10974, Idaho National Engineering Laboratory.

Magnuson, S. O. and D. L. McElroy, 1993, "Estimation of Infiltration from In Situ Moisture Contents and Representative Moisture Characteristic Curves for the 30', 110', and 240' Interbeds," EDF-RWM-93-001, Idaho National Engineering Laboratory.

Magnuson, S. O. and A. J. Sondrup, 1998, *Development, Calibration, and Predictive Results of a Simulator for Subsurface Pathway Fate and Transport of Aqueous- and Gaseous-Phase Contaminants in the Subsurface Disposal Area at the Idaho National Engineering and Environmental Laboratory*, INEEL/EXT-097-00609, Idaho National Engineering and Environmental Laboratory.

Mann, Larry J. and T. M. Beasley, 1994, *Iodine-129 in the Snake River Plain Aquifer at and near the Idaho National Engineering Laboratory, Idaho, 1990-91*, USGS Water-Resources Investigations Report 94-4053, U.S. Geological Survey, DOE/ID-22115, U.S. Department of Energy Idaho Operations Office.

Manual 8, 2006, *Environmental Protection and Compliance*, Rev. 76, Idaho National Laboratory.

Martian, P. and S. O. Magnuson, 1994, *A Simulation Study of Infiltration Into Surficial Sediments at the Subsurface Disposal Area, Idaho National Engineering Laboratory*, EGG-WM-11250, Idaho National Engineering Laboratory.

McDaniel, P. A., 1991, *Interpretation of Soil Properties at the RWMC and Spreading Area Sites, Idaho National Engineering Laboratory*, University of Idaho, Moscow, Idaho.

McElroy, D. L., 1990, *Vadose Zone Monitoring at the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory 1985-1989,* EGG-WM-9299*,* Idaho National Engineering Laboratory.

McElroy, D. L., 1993, *FY 1993 Soil Moisture Monitoring Results at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory*, EGG-WM-11066, Idaho National Engineering Laboratory.

McElroy, D. L., 1996, *Subsurface Disposal Area Perched Water Level Data Compilation,* INEL-96-226, EDF-RWMC-901, Idaho National Engineering Laboratory.

McElroy, D. L. and J. M. Hubbell, 1990, *Hydrologic and Physical Properties of Sediments at the Radioactive Waste Management Complex*, EGG-BG-9147, Idaho National Engineering Laboratory.

McElroy, Deborah L. and Joel M. Hubbell, 2001, *Radioactive Waste Management Complex Tensiometer Status as of November 2000*, INEEL/EXT-01-01624, Idaho National Engineering and Environmental Laboratory.

McElroy, Deborah L. and Joel M. Hubbell, 2004, *Fiscal Year 2003, OU 7-13/14 Advanced Tensiometer Monitoring results from the Deep Vadose Zone at the Radioactive Waste Management Complex*, ICP/EXT-04-00241, Idaho National Laboratory, Idaho Completion Project.

McElroy, D. L. and J. M. Hubbell, 2004a, "Evaluation of the Conceptual Flow Model for a Deep Vadose Zone System Using Advanced Tensiometers," *Vadose Zone Journal*, Vol. 3, pp. 170–182.

McElroy, D. L. and J. M. Hubbell, 2004b, *Fiscal Year 2003, OU 7-13/14 Advanced Tensiometer Monitoring results from the Deep Vadose Zone at the Radioactive Waste Management Complex*, ICP/EXT-04-00241, Idaho National Laboratory, Idaho Completion Project.

McKinney, J. D., 1985, *Big Lost River 1983-1984 Flood Threat*, PPD-FPB-002, Idaho National Engineering Laboratory.

MCP-553, 2006, "Stop Work Authority," Rev. 10, Idaho National Laboratory.

MCP-3480, 2005, "Environmental Instructions for Facilities, Processes, Materials and Equipment," Rev. 10, Idaho National Laboratory, Idaho Cleanup Project.

Meyer, T. J., Danny L. Anderson, Carolyn W. Bishop, John R. Giles, Joel M. Hubbell, Richard L. Jones, Nick Josten, and A. Jeffrey Sondrup, 2005, *Final Report for the Waste Area Group 7 Probing Project*, ICP/EXT-05-00784, Idaho National Laboratory, Idaho Cleanup Project.

Mitchell, T., S. Mitchell, J. Humphrey, D. Kennedy, and T. Funderburg, 2001, *100-Year Floodplain and 25-Year Runoff Analyses for the Radioactive Waste Management Complex Area at the Idaho National Engineering and Environmental Laboratory*, INEEL/EXT-02-00093, Idaho National Engineering and Environmental Laboratory.

Nimmo, John R., Kim S. Perkins, Peter E. Rose, Joseph P. Rousseau, Brennon R. Orr, Brian V. Twining, and Steven R. Anderson, 2002, "Kilometer-Scale Rapid Transport of Naphthalene Sulfonate Tracer in the Unsaturated Zone at the Idaho National Engineering and Environmental Laboratory," *Vadose Zone Journal*, Vol. 1, No. 1, pp. 89–101.

Oberhansley, Gary G., 2004, *Well Completion Report for the Operable Unit 7-13/14 Vapor Port and Lysimeter Monitoring Wells (RWMC-2004, RWMC-2005 and RWMC-2006) for Fiscal Year 2004*, ICP/EXT-04-00604, Idaho National Engineering and Environmental Laboratory, Idaho Completion Project.

Oberhansley Gary and Joel M. Hubbell, 2005, *Well Completion Report for OU7-13/14 Wells RWMC-1935 and RWMC-1936 Near the Radioactive Waste Management Complex for Fiscal Year* 2004, ICP/EXT-04-00624, Rev. 0, Idaho National Engineering and Environmental Laboratory, Idaho Completion Project.

Ostenaa, D. A., D. R. Levish, R. E. Klinger, and D. R. H. O'Connell, 1999, *Phase 2 Paleohydrologic and Geomorphic Studies for the Assessment of Flood Risk for the Idaho National Engineering and Environmental Laboratory, Idaho*, Report 99-7, Geophysics, Paleohydrology, and Seismotectonics Group, Technical Service Center, U.S. Bureau of Reclamation, Denver, Colorado.

Ostenaa, D. A. and D. R. H. O'Connell, 2005, *Big Lost River Flood Hazard Study Idaho National Laboratory, Idaho*, Report 2005-2, Seismotectonics and Geophysic Group, Technical Service Center, U.S. Bureau of Reclamation, Denver, Colorado.

Parsons, 1995a, *Pad A Limited Action Long-Term Monitoring Plan*, Operable Unit 7-12, INEL-95/0271, Parsons Document No. ES-#14.6.9.8, Rev. 5, prepared by Parsons Engineering Science for the Idaho National Engineering Laboratory.

Parsons, 1995b, *Remedial Action Report Pad A Limited Action Operable Unit 7-12*, INEL-95/0313, Parsons Document No. 07.012.0.320.01, Rev. 2, prepared by Parsons Engineering Science for the Idaho National Engineering Laboratory.

Parsons, T., G. A. Thompson, and R. P. Smith, 1998, "More Than One Way to Stretch: A Tectonic Model for Extension Along the Track of the Yellowstone Hotspot and Adjacent Basin and Range Province," *Tectonics*, Vol. 17, No. 2, pp. 221–234.

Payne, S. J., V. W. Gorman, S. A. Jensen, M. E. Nitzel, M. J. Russell, and R. P. Smith, 2002, *Development of Probabilistic Design Basis Earthquake (DBE) Parameters for Moderate and High Hazard Facilities at INEEL*, INEEL/EXT-99-00775, Rev. 2, Idaho National Engineering and Environmental Laboratory.

Pelton, J. R., R. J. Vincent, and N. J. Anderson, 1990, "Microearthquakes in the Middle Butte/East Area, Eastern Snake River Plain, Idaho," *Bulletin of the Seismological Society of America,* Vol. 80, pp. 209–212.

Pierce, K. L. and L. A. Morgan, 1992, "The Track of the Yellowstone Hotspot: Volcanism, Faulting, and Uplift," *Regional Geology of Eastern Idaho and Western Wyoming,* Geological Society of America Memoir, Vol. 179, pp. 1–53.

Reynolds, T. D. and P.A. Richards, 1996, "Unit Operations and Processes in Environmental Engineering," *PWS*, 2nd ed.

Rightmire, C. T. and B. D. Lewis, 1987, *Hydrogeology and Geochemistry of the Unsaturated Zone, Radioactive Waste Management Complex, Idaho National Engineering Laboratory, Idaho*, USGS Water-Resources Investigations Report 87-4198, U.S. Geological Survey, DOE/ID-22073, U.S. Department of Energy Idaho Operations Office.

Ringe, B. L., 1995, *Locational Analysis and Preliminary Predictive Model for Prehistoric Cultural Resources on the Idaho National Engineering Laboratory*, Administrative Record No. 115951, M.S. Thesis: Department of Anthropology, Idaho State University, Pocatello, Idaho.

Ritter, P. D. and D. L. McElroy, 1999, *Progress Report: Tritium and Carbon-14 Sampling at the Radioactive Waste Management Complex*, INEEL/EXT-98-00669, Rev. 0, Idaho National Engineering and Environmental Laboratory.

Roddy, Michael S. and L. Don Koeppen, 2004, *Evaluation of Aquifer Contaminants Upgradient from the Radioactive Waste Management Complex*, ICP/INT-04-00285, Idaho National Engineering and Environmental Laboratory, Idaho Completion Project.

Roddy, Michael, 2005, "Geochemical Study for Perched Water Source Identification at INTEC," EDF-5758, Rev. 0, Idaho National Laboratory, Idaho Cleanup Project.

Sagendorf, J., 1996, *Precipitation Frequency and Intensity at the Idaho National Engineering Laboratory*, ARLFRD 94-100, U.S. Department of Commerce, National Oceanic Atmospheric Administration, Environmental Research Laboratories, Air Resources Laboratory Field Research Division, Idaho Falls, Idaho.

Smith, R. P., S. M. Jackson, and W. R. Hackett, 1996, "Paleoseismology and Seismic Hazards Evaluations in Extensional Volcanic Terrains," *Journal of Geophysical Research*, Vol. 101, No. B3, pp. 6,277–6,292.

Sorenson, K., L. Peterson, R. Hinchee, and R. Ely, 2000, "An Evaluation of Aerobic Trichloroethene Attenuation Using First-Order Rate Estimation," *Bioremediation Journal*, Vol. 4, pp. 337–357.

Stacy, S. M., 2000, *Proving the Principle: A History of the Idaho National Engineering and Environmental Laboratory 1949-1999*, DOE/ID-10799, U.S. Department of Energy Idaho Operations Office.

State of Idaho, 2005, *State of Idaho Homepage*, URL: http://www.state.id.us/, Web page last visited May 2006.

Stoller, 2002, *INL Environmental Surveillance, Education and Research Program*, S. M. Stoller Corporation, URL: http://www.stoller-eser.com, Web page last visited May 2006.

U.S. Government, 1868, *Treaty with the Shoshonee and Bannacks, July 3, 1868,* URL: http://www.windriverhistory.org/archives/treaty_docs/docs/1868-treaty.pdf, Web page last visited May 2006.

USGS, 2005a, *National Seismic Hazard Maps*, URL: http://eqhazmaps.usgs.gov/, Web site last visited May 2006.

USGS, 2005b, *Surface-Water Data for Idaho*, USGS Water Resources of Idaho, U.S. Geological Survey, URL: http://waterdata.usgs.gov/id/nwis/sw?, Web page last visited May 2006.

Van Horn, R. L., N. L. Hampton, and R. C. Morris, 1995, *Guidance Manual for Conducting Screening Level Ecological Risk Assessments at the INEL*, INEL-95/0190, Rev. 0, Idaho National Engineering Laboratory.

Wilcyski, J. M. and Keith Tinno, 1998, *Agreement in Principle between Shoshone-Bannock Tribes and United States Department of Energy*, U.S. Department of Energy, Shoshone-Bannock Tribes.

Wood, Thomas R. and Gregory. T. Norrell, 1996, *Integrated Large-Scale Aquifer Pumping and Infiltration Tests, Groundwater Pathways OU 7-06, Summary Report*, INEL-96/0256, Rev. 0, Idaho National Engineering Laboratory.

Wylie, A. H., 1996, *Pumping Test of Pit 9 Production Well*, INEL-96/171, Idaho National Engineering Laboratory.

Wylie, A. H. and J. M. Hubbell, 1994, "Aquifer Testing of Wells M1S, M3S, M4D, M6S, M7S, and M10S at the Radioactive Waste Management Complex," ER-WAG7-26, Rev. 1, Idaho National Engineering Laboratory.

Wylie, A. H., E. Neher, J. M. McCarthy, and B. D. Higgs, 1995, "Large-Scale Aquifer Pumping Test Results," EDF ER-WAG7-56, Idaho National Engineering Laboratory.